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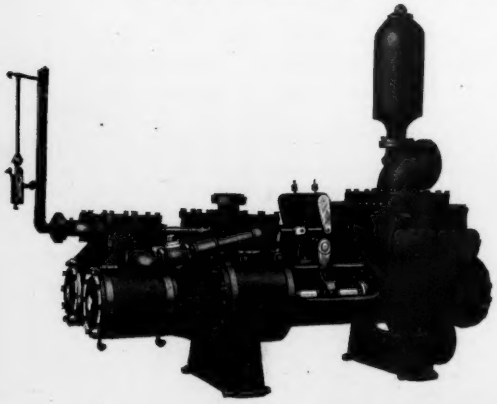
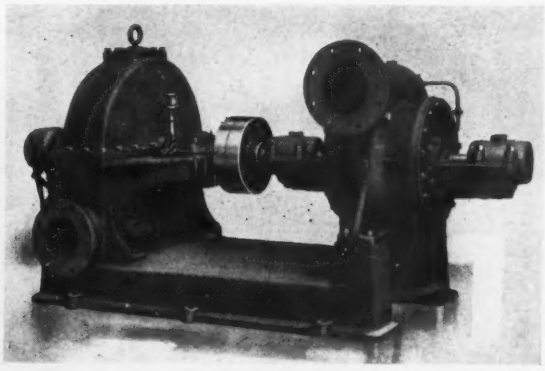
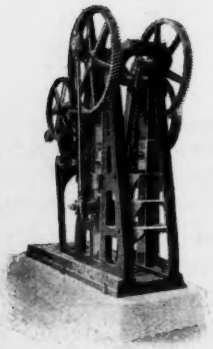
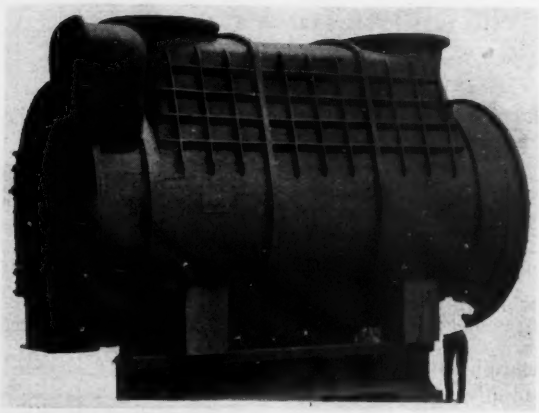
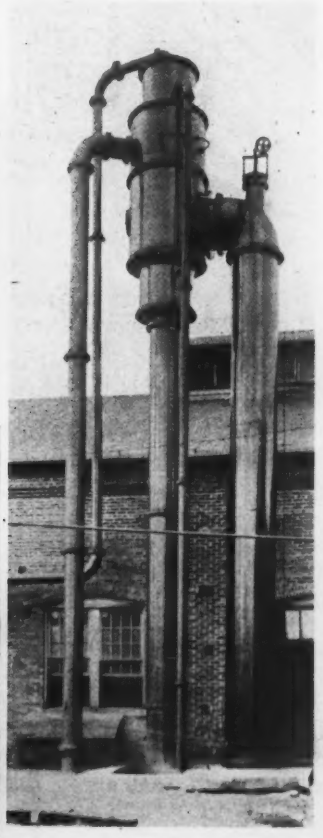
Types of Pumps, Condensers and Cooling Systems

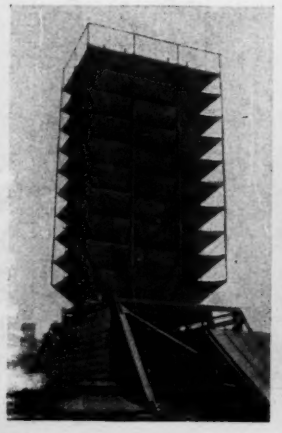






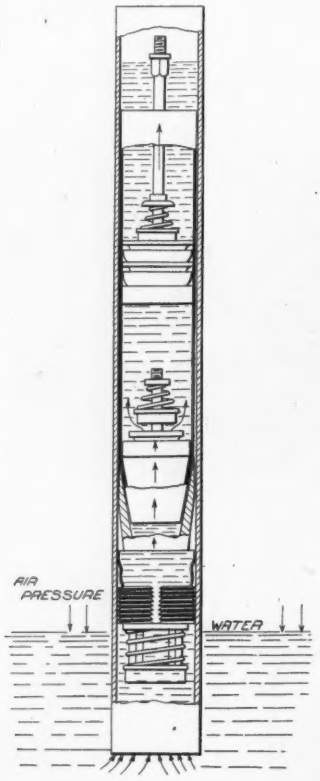






Principles of Reciprocating Steam Pumps

IN PRACTICALLY ALL PUMPS which come under this classification, the handling of water is divided into 2 parts, first, the suction, second, the discharge. While the liquid may come to the suction under a pressure or head, and in the case of hot liquid must do so, as a rule, it comes to the pump by suction, that is, by creating a partial vacuum in the pump cylinder, into which liquid



ACTION OF DEEP WELL BUCKET PUMP IN SUCTION BY LIFT

is forced by the pressure of the atmosphere on the surface of the liquid at the source of supply.

Suction Lift

THE HEIGHT to which water may be drawn by suction depends on the amount of atmospheric pressure available, and while a 30-in. barometer is theoretically equivalent to a 34-ft. head of water, actually no such suction lift can be secured, because of air leakage, friction, and the fact that a perfect vacuum can never be attained in the pump. As 30 in. of mercury equals 14.7 lb. absolute pressure, and as 1 lb. of pressure is the equivalent of 2.31 ft. head of water, it follows that 1 in. of mercury pressure of atmosphere will be equivalent to 1.132 ft. suction head of water, but it is found in practice, that each inch of mercury pressure can actually support about 0.8 ft. head of water. This makes for a 30-in. barometer, an actual possible lift of 24 ft. maximum when pumping water. For pumping other liquids, the suction head possible is in proportion to the specific gravity of the liquid.

It follows, also, from this, that at high altitudes, where the barometric pressure is less than 30 in., the possible suction is less than at sea level, and the relations of altitude, barometric pressure, theoretical and practical lifts are given in Table I.

In the handling of hot water, the boiling point enters; at atmospheric pressure, water turns into steam at 212 deg., but for a 24-in. vacuum, which is equivalent to 2.94 lb. absolute pressure, the boiling temperature is 141 deg. F., for 26 in. vacuum, boiling temperature is

BALL TYPE VALVE FOR DEEP WELL BUCKET. DESIGN OF AMERICAN WELL WORKS

TABLE I. BAROMETRIC PRESSURES, ALTITUDES, WITH THEORETICAL AND PRACTICAL CORRESPONDING SUCTION PIPES

Barom. In.Hg.	Altitude Above Sea, Ft.	Atmos. Press. Lb.Sq.In.	Equiv.Hd. of Water, Ft.	Practical Suc'n.Lift, Ft.
30.0	0	14.72	33.96	24.1
29.5	466	14.47	33.40	23.6
29.0	941	14.23	32.82	23.2
28.5	1424	13.98	32.23	22.8
28.0	1915	13.74	31.68	22.4
27.5	2415	13.50	31.10	22.0
27.0	2924	13.26	30.50	21.6
26.5	3443	13.02	30.00	21.2
26.0	3972	12.77	29.40	20.8
25.0	5061	12.27	28.25	20.0
24.0	6194	11.78	27.15	19.2
23.0	7375	11.30	26.00	18.4
22.0	8609	10.80	24.87	17.6
21.0	9900	10.31	23.76	16.8
20.0	11,254	9.81	22.63	16.0
19.0	12,678	9.32	21.49	15.2
18.0	14,179	8.82	20.36	14.4
17.0	15,766	8.33	19.24	13.6
16.0	17,448	7.84	18.11	12.8
15.0	19,240	7.35	16.98	12.0
14.0	21,155	6.86	15.85	11.2
13.0	23,212	6.37	14.71	10.4
12.0	25,433	5.88	13.58	9.6
11.0	27,848	5.39	12.44	8.8
10.0	------	4.91	11.32	8.0

125 deg., and for 29 in. vacuum, 79 deg. F. The effective pull, or suction of a pump is greater before the liquid starts to flow than after the liquid is once flowing, on account of friction, hence the temperature

TABLE II. VARIATION OF CALCULATED AND PRACTICAL SUCTION LIFT WITH WATER TEMPERATURE

Vacuum Ref.to 30" Barom., In.	Abs.Press. in Suc'n. Pipe, Lb.Sq.In.	Calculated Lift, Ft. Hd.	Practical Lift, Ft. Hd.	Max.Temp. of Suc'n. Water, Deg. F.	Practical Temp. of Suction, Deg. F.
1	14.21	1.13	0.8	210	156
2	13.72	2.26	1.6	208	152
3	13.23	3.40	2.4	207	148
4	12.74	4.53	3.2	205	143
5	12.25	5.66	4.0	203	140
6	11.76	6.80	4.8	201	137
7	11.27	7.93	5.6	199	132
8	10.78	9.07	6.4	197	129
9	10.29	10.20	7.2	195	124
10	9.80	11.32	8.0	192	122
11	9.31	12.44	8.8	190	118
12	8.82	13.58	9.6	187	115
13	8.33	14.71	10.4	185	111
14	7.84	15.85	11.2	182	108
15	7.35	16.98	12.0	179	104
16	6.86	18.11	12.8	176	100
17	6.37	19.24	13.6	173	97
18	5.88	20.36	14.4	169	94
19	5.39	21.49	15.2	165	90
20	4.90	22.63	16.0	161	87
21	4.41	23.76	16.8	157	83
22	3.92	24.87	17.6	152	79
23	3.43	26.00	18.4	147	77
24	2.94	27.10	19.2	141	73
25	2.45	28.25	20.0	134	69
26	1.96	29.40	20.8	125	67
27	1.47	30.54	21.6	115	63
28	0.98	31.68	22.4	101	57
29	0.49	32.82	23.2	79	53
30	0.00	33.95	24.1		

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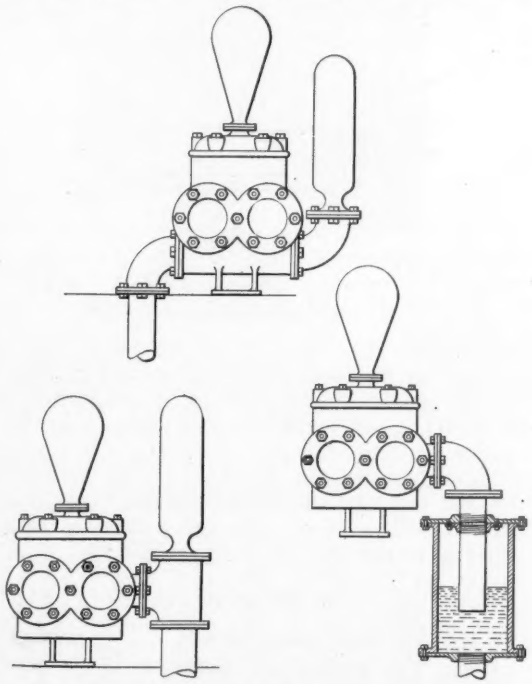
of water which can be lifted at these various suctions, is considerably less than that theoretically indicated, and as a matter of fact, it is found that water above 150 deg. cannot be handled at all by suction, but must come to the pump inlet under pressure. Table II shows the relation between vacuum, absolute pressure in the suction pipe, calculated and practical lifts, the maximum temperature of suction water that can theoretically be handled, and the practical temperature of the suction water and Table III shows the head under which water must come to the inlet at temperatures above 160 deg.

TABLE III. NECESSARY INLET HEADS FOR WATER OVER 160 DEG. F.

Temp. of Inlet Water Deg. F.	165	170	175	180	185	190	195	200	205	210
Practical Suction Pressure Head Ft.	1.6	2.7	3.8	5	6	7	8	9.2	10.3	11.5

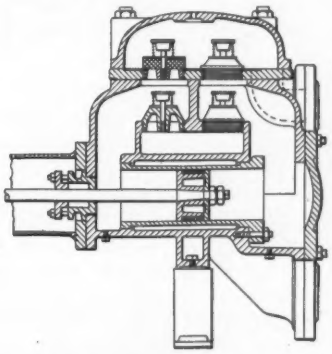
When it is necessary to pump against a suction lift greater than that shown in Table I, air may be admitted with the water to form a heavy spray, and as much as 100 ft. suction lift may be handled in this way by having all suction joints tight. Air should be admitted through several small openings a little above the water level of the supply, to get a uniform mixture, and such a condition usually requires priming of the pump when starting. This method reduces the weight per cubic foot of the mixture, and increases possible suction head in proportion, but it reduces the capacity of the pump, since air must be handled as well as water. For such a pump, the valves must be made as for air pumps on condensers, and the pump does not, therefore, permit of a high forcing head; a larger pump must be used, for a given capacity, than ordinarily, and the pump must be run at high speed.



ARRANGEMENT OF SUCTION AIR CHAMBER TO CUSHION IN DIRECTION OF FLOW

Suction in the pump cylinder is produced either by a bucket lift with clapper or ball valves, as in the ordinary house pump, the deep well pump, or the pit pump for mines; or by the displacement method of withdrawing the piston or plunger from the suction side of the cylinder, thus creating a vacuum into which the water or other liquid flows through the suction valves, being forced by the atmospheric pressure.

If the suction is difficult, due either to the temperature of the water or to the friction in the suction system, it is evident that a high speed of working cannot be attained, hence the speed of the pump is usually limited by the velocity of liquid possible in the suction system. This friction depends on the area of the suction pipe, the area of the valves and passages in the pump, and the velocity of flow of the liquid. Since most of the pumping in a power plant is for water or a liquid of similar density, it will suffice to study the action of water and to determine the friction losses,



PISTON PUMP END WITH REMOVABLE CYLINDER LINING, END INLET AND DISCHARGE CONNECTION AND BOLTED STUFFING BOX

and other causes of loss of head in the suction system. In addition to the friction, there is the question of stopping and starting the column of water as the pump reverses, and a long column starts and stops slowly, due to the momentum, hence the longer the suction pipe, the slower must be the speed of working. Some help can be secured by the use of the suction air chamber, which gives a cushion to take up the momentum at stopping, and to assist the flow at starting. When such a chamber is used, it should be placed in line with the flow of the water, as shown in the illustrations herewith, the volume of the chamber being twice the piston displacement of the pump. Preferably it has a diameter a little larger than that of the pipe, with length to give the required volume, and the neck of the suction air chamber ⅓ the diameter of the chamber itself.

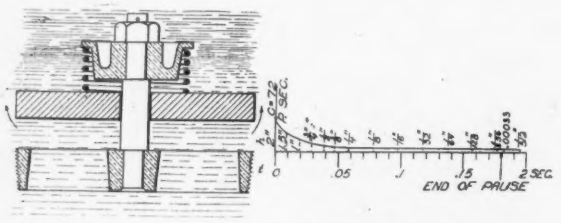
Suction Pipe Size

Velocity of water in the suction pipe is from 100 to 200 ft. a minute, depending on the size of the pipe. In practice it will usually vary from 150 ft., for small pumps, up to 250 ft. in the largest pumping plants.

Where 250 ft. a minute is used, a convenient expression given by Nickel for the diameter of the suction pipe is, the square root of (0.1 times the gallons pumped per minute). To determine the diameter of the suction pipe for any velocity, Kent gives the rule: Divide the gallons per minute by the velocity in feet per minute; extract the square root of the quotient, and multiply by 4.95. The result will be the diameter of the suction pipe in inches.

Pump Slip

Another practical limitation to the speed of a pump, which applies to both suction and discharge ends, is the seating of the valves. Evidently the valves do not close immediately when the pump reaches the end of the stroke, and stops, for the reason that the water passing through the valves has some inertia and will continue to flow for an instant, also the valves, which are at their highest position, take a slight amount of time to get in motion, and after they start moving, the water between the valves and their seats must be displaced, which takes place by a gradual action. Practically the valve never comes in metal contact with the seat while the pump is running, for it would require an infinite amount of time for all of the water to be displaced, but the film becomes so thin after a short interval that the water



ACTION OF DISK VALVE IN DISPLACING WATER AS IT SEATS

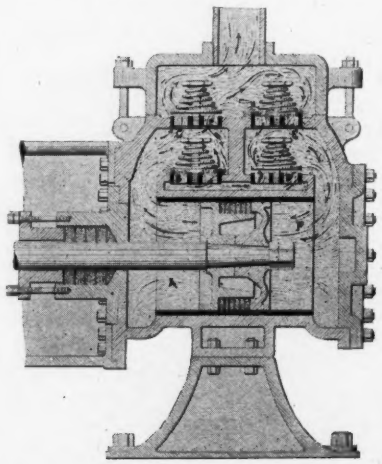
will not pass between the valve and seat. Until the valve has closed to this point, however, there will be a flow of water through the valve in one direction or the other. If the pump did not reverse its motion, the water would continue to flow on through the suction valves and also the discharge valves, due to the inertia of the water. If, however, the pump reverses, the tendency will be to draw water back through the discharge valves and force water out through the suction valves, until these valves become seated sufficiently to prevent such flow. It is necessary, therefore, in order to avoid back flow, or slip, through the valves, to give time at the end of the stroke for the valves to seat properly, and this limits the number of reversals that a pump may have per minute, and still get satisfactory performance.

As seen in the cut, which was furnished by courtesy of the Leavitt Machine Co., while the end A of the pump cylinder is discharging, valve B is closed and valve C is opened, while at the other end, valve B is opened to admit water to the end of the cylinder and valve C is closed. If valves B and E are not seated, or the seats are worn, there will be tendency for the water to be forced back through valve B into the suction, and to be drawn through valve E from the discharge chamber.

If the piston is not tight, there will be tendency for water to leak past the piston from end A to the end F. All this loss is usually lumped together under the term "slip," but properly should be separated into 2 parts, first, the slip proper, due to the slow closing of the valves, second, the leakage, which is due to worn valve seats or to poor piston fit and is continued throughout the stroke. It is evident that the slip will be practically a constant percentage of the piston displacement, whatever the speed, while the leakage will be a much larger per cent at low speed than at high.

Slip is usually reckoned as a percentage of piston displacement, the piston displacement being equal to the area of the piston times the stroke, and the volumetric efficiency of the pump is therefore equal to 1 minus the slip. The slip may run from 5 to as high as 20 per cent, but should not be over 10 per cent for a pump in fair condition, and by careful oversight may be kept down to 5 per cent.

Evidently the higher the valves rise from their seats, the longer will be the time required for them to seat, and the greater the amount of slip at reversal. Also, the higher the valve lifts, the greater will be the opening through which the water may pass between the valve and seat, and the less the friction, and the valve lift to be used becomes a compromise between these two conflicting factors, as will be discussed later.



ACTION OF PISTON IN SUCKING AND FORCING AND LEAKAGE THROUGH VALVES. NOTE PISTON CONSTRUCTION, CYLINDER HEAD AND FRAME BOLTING, FORCED IN CYLINDER LINING AND STUFFING BOX BOLTED ON; OVERHEAD VALVE DECKS

Classes of Pumps

Water and steam pumps are in general divided into 3 classes, the bucket, the piston and the plunger, according to the means by which water is moved in the pump cylinder. In the bucket pump, the valve is placed directly in a moving part, and the motion is usually vertical, water flowing through the valve on the down stroke, and being lifted by the closed valve and the bucket on the up stroke. For such pumps, the valves used in the bucket are usually of the clapper or ball type, although some bucket pumps, particularly for vacuum pumps in condensers, which have large buckets, or vertical acting pistons, are provided with the poppet type of disk valve, working on the upper surface of the piston. In such a pump, a foot valve is needed at the

bottom of the suction pipe, particularly for long lifts, in order to hold the water in the suction pipe while the bucket is making its down stroke.

In both piston and plunger type, suction and discharge valves are located in decks outside the pump cylinder. In the piston pump, the moving part is drawn back and forth in a bored cylinder, the joint being between the outside of the piston and the inside of the cylinder, and usually kept tight either by some kind of fibrous packing or by snap rings on the outside of the piston. In the plunger type, the moving part is drawn back and forth in the cylinder, but a joint is provided either by a close fitting renewable ring or by a soft packing which fits around the outside of the plunger and is held against it by a stuffing box and gland. In these pumps, it is not necessary to have a foot valve in the suction pipe, unless that pipe be of great length.

TABLE IV. DISPLACEMENT PER 1 IN. OF STROKE

Diam. Piston or Plunger, In.	Gal. per 1 in. of Stroke	Diam. Piston or Plunger, In.	Gal. per 1 in. of Stroke
2	0.014	9	0.285
3	0.031	10	0.340
4	0.055	12	0.490
5	0.085	14	0.660
6	0.122	16	0.870
7	0.166	18	1.100
8	0.218	20	1.360

The bucket type of pump can lift against only moderate discharge heads, and is not usually used for large capacities. It is ordinarily a slow moving pump, and has rather long stroke and small diameter. The piston pump is inexpensive, compact, and can be used for discharge heads up to 300 lb. pressure, but is not usually used above 150 lb., on account of difficulty in keeping the piston tight. The plunger type is used for all high-pressure work, and while a larger and more expensive pump, it is easier to keep in repair, and by careful construction may be used against any discharge pressure. Where the pressures run above 500 lb. to the square inch, it is usual to employ what are known as "pot" valves, having separate small valve chambers for the suction and discharge valves, and if the head is more than 2000 lb., the metal used must be carefully watched, as well as the packing of joints and plungers. Up to 3000 lb. pressure, castings are usually used. For pressures above that, all parts are made of forged steel, and the cylinders and chambers are bored from the solid metal.

TABLE V. RELATION OF UNITS FOR WATER

		Cu. Ft.	Lb.	Gall.	Cu. In.
Cu. Ft.	1	1	62.4	7.48	1728
Lb.	1	0.016	1	0.083	27.7
Gall.	1	0.134	8.33	1	231
Cu. In.	1	0.00058	0.0361	0.00433	1

TABLE VI. AVERAGE SLIP AND EFFICIENCY OF PUMPS

Kind of Pump	Average Slip %	1 - Slip = Vol. Eff. %	Total Eff. %
Deep Well	12	88	80
Ordinary Piston	15	85	70
Small "	20	80	70
Triplex Power	20	80	75
Large Centrifugal	20	80	70
Medium "	40	60	70
Small "	60	40	70

Pump Capacity

IT IS evident that slip and leakage reduce the capacity of the pump, and are, therefore, a detriment not only in the matter of efficiency but in the quantity of liquid delivered. To determine the pump capacity, the simplest method is to multiply the piston displacement in gallons or in cubic feet, as may be desired, by the strokes per minute, the result being the gallons or cubic feet per minute. This would be the theoretical capacity, but the actual is from 65 to 95 per cent of this, depending upon the speed at which the pump is run, the tightness of the joints, and the pressure under which it operates.

As practical formulas, Kent gives the following: Gallons per minute will be equal to 0.0034 times the strokes per minute times the square of the diameter of the cylinder in inches, times the length of the stroke in inches. For gallons per hour use the constant 0.204 in the preceding, in place of 0.0034. For cubic feet per minute, use the constant 0.0004545 in place of 0.0034.

Since there is always the question, when strokes per minute are mentioned, whether single or double strokes are meant, and particularly in the case of duplex pumps, which have 2 pump cylinders, whether the strokes of one cylinder or of both are intended, it is now common to speak of the revolutions per minute, or r.p.m. of a reciprocating pump, a revolution being taken from the time when one piston starts on its forward stroke until that same piston starts on its next forward stroke. This gives in the case of a single cylinder pump 2 single strokes to a revolution, and for a duplex pump, 4 single strokes. It is simpler, however, to figure the capacity of each cylinder and then multiply by the number of cylinders, and to get the practical capacity in gallons per minute, we would multiply the displacement per inch of stroke by the length of the stroke, by the number of strokes per minute, by the slip, and by the number of cylinders. Slip will vary with the kind of pump, and the displacement per inch of stroke with the diameter. Table IV gives the displacement per inch of stroke for the most commonly used diameters of pistons and plungers, and Table V gives the relations of units for water, making it possible to convert between cubic feet, pounds, gallons and cubic inches in either direction by the use of the proper multiplier.

As already stated, slip may be from 5 to 20 per cent, and the volumetric or water efficiency will be equal to 1 — slip. There is also the mechanical efficiency to be considered, which is due to the friction of the moving parts, and this will vary largely for different types of pumps; and total efficiency equals volume efficiency times mechanical efficiency. Table VI gives the slip, 1 minus the slip, or the volumetric efficiency, and the total efficiency for various types. It will be understood that these values are approximate, and give a general idea only of what may be expected in any given case.

To determine the work done in the water end of a pump, multiply the weight of water lifted by the height to which it is lifted; this height, or head, must be the sum of suction and discharge heads, remembering that the suction head may be taken negative if the water comes to the pump under pressure. As 1 gal. of water weighs 8.33 lb., the work will then equal the gallons

times 8.33 times the head in feet, or will equal the cubic feet times 62.4 times the head in feet, this head being from the surface of water in the suction reservoir to the highest discharge point. If in the place of head of water we wish to use pounds pressure, we substitute in the above expression for head in feet, the pressure per square inch times 2.31, since one pound pressure is equal to 2.31 ft. head of water. The water horsepower will then be the work per minute divided by 33,000, or the work per hour divided by 198,000.

Total efficiency given in the Table VI will be the water horsepower divided by steam horsepower, or the water horsepower divided by the mechanical horsepower of a belted or geared pump.

TABLE VII. HEAD, PRESSURE AND HORSEPOWER AT DIFFERENT HEADS FOR PUMPING WATER

Total Pressure		Horsepower for 100 Gal. Per Min.		Horsepower for 100 Cu. Ft. Per Min.	
Lb. Per Sq. In.	Head Ft.	Theoretical	Pump Eff. 55%	Theoretical	Pump Eff. 55%
.43	1.00	0.025	0.046	0.19	0.34
.86	2.00	0.050	0.092	0.38	0.68
1.00	2.31	0.058	0.106	0.44	0.79
1.30	3.00	0.075	0.138	0.57	1.03
1.73	4.00	0.101	0.183	0.76	1.37
2.00	4.62	0.117	0.212	0.87	1.59
2.16	5.00	0.125	0.228	0.95	1.70
2.59	6.00	0.150	0.275	1.60	2.05
3.00	6.93	0.175	0.318	1.31	2.38
3.03	7.00	0.176	0.322	1.34	2.40
3.46	8.00	0.201	0.367	1.52	2.74
3.89	9.00	0.225	0.413	1.74	3.07
4.00	9.24	0.233	0.424	1.75	3.17
4.33	10.00	0.251	0.460	1.91	3.42
5.00	11.55	0.292	0.530	2.18	3.97
6.00	13.86	0.350	0.636	2.62	4.76
7.00	16.17	0.408	0.742	3.05	5.55
8.00	18.48	0.467	0.848	3.49	6.35
8.66	20.00	0.501	0.920	3.82	6.84
9.00	20.79	0.525	0.955	3.93	7.14
10.00	23.10	0.583	1.061	4.36	7.93
12.99	30.00	0.753	1.380	5.75	10.26
17.32	40.00	1.004	1.840	7.64	13.70
20.00	46.20	1.167	2.121	8.73	15.90
21.65	50.00	1.255	2.300	9.55	17.10
25.99	60.00	1.506	2.760	11.50	20.50
30.00	69.30	1.750	3.180	13.10	23.80
30.32	70.00	1.760	3.220	13.40	23.90
34.65	80.00	2.010	3.680	15.30	27.40
38.98	90.00	2.260	4.140	17.20	30.80
40.00	92.40	2.330	4.240	17.40	31.70
43.31	100.00	2.510	4.600	19.10	34.20
50.00	115.50	2.920	5.300	21.80	39.70
60.00	138.60	3.500	6.360	26.20	47.60
70.00	161.70	4.080	7.420	30.60	55.50
80.00	184.80	4.670	8.490	34.90	63.50
86.60	200.00	5.010	9.200	38.20	68.40
90.00	208.00	5.250	9.550	39.50	71.40
100.00	231.00	5.830	10.610	43.60	79.30
130.00	300.00	7.580	13.790	56.70	103.10
173.00	400.00	10.040	18.400	76.40	136.80
200.00	462.00	11.670	21.200	87.30	158.70
216.50	500.00	12.550	23.000	95.50	171.00
260.00	600.00	15.170	27.600	113.50	206.30
300.00	693.00	17.500	31.800	130.90	238.00
303.20	700.00	17.600	32.200	133.70	239.40
346.50	800.00	20.100	36.800	152.80	273.60
389.80	900.00	22.600	41.400	171.90	307.80
400.00	924.00	23.300	42.400	174.50	317.40
433.00	1000.00	25.100	46.000	191.00	342.00
500.00	1155.00	29.200	53.000	218.20	396.70
600.00	1386.00	35.000	63.600	261.80	476.00
700.00	1617.00	40.800	74.200	305.50	555.40
800.00	1848.00	46.700	84.900	349.00	635.00
866.00	2000.00	50.100	92.000	382.00	684.00
900.00	2079.00	52.500	95.500	393.00	714.00
1000.00	2310.00	58.300	106.100	436.00	793.00

Table VII herewith shows the relation between the pounds pressure per square inch and the head of water in feet, and gives also the horsepower required to lift 100 gal. of water a minute or 100 cu. ft. a minute, both the theoretical water horsepower and the indicated or mechanical horsepower with a total pump efficiency of 55 per cent. Values for intermediate heads or pressures can be readily obtained by adding together the values for the partial heads, and for other volumes by multiplying by the number of hundreds of gallons or cubic feet to be handled.

Table VIII gives a brief average of sizes and capacities most commonly used for boiler feeding, speeds being such as to give easy working.

Pump Performance Chart

In the chart herewith for pump capacities and performance, starting at the left hand margin of the lower part, with the diameter of the cylinder in inches follow to the right until the diagonal line for stroke is crossed, then vertically downward, to find the displacement per stroke in gallons. To find the piston displacement per minute in gallons, follow upward from intersection with the stroke diagonal to the 45-deg. diagonal, representing the proper number of strokes per minute, and then to the left to the piston displacement per minute axis in gallons. To take account of the slip, stop where the horizontal crosses the diagonal for the per cent of slip estimated, and pass vertically downward to the gallons of water per minute axis, which will give the actual gallons pumped. To determine the water horsepower, instead of passing downward from the slip diagonal, pass upward to the diagonal representing the head against which the pump is working, either in feet or pounds pressure, then to the right and read on the water horsepower axis the power delivered. To find the power supplied stop at the diagonal representing the estimated efficiency and pass vertically downward to the steam or mechanical horsepower axis and read the horsepower which must be supplied. In the case of a direct acting steam pump to determine the steam necessary, pass to the line representing steam per horsepower per hour, then to the left, and read the total steam required per hour on the left hand axis.

TABLE VIII. CAPACITIES OF PUMPS FOR BOILER FEEDING

MAX. BOILER FEED PUMP CAPACITIES

Boiler H.P. of 30 Lb. Per Hr.

Diam. In.	Stroke In.	Single Cyl.	Duplex Cyl.
2	3		45
2	4	50	75
3	5		190
3	6	130	
3½	5		240
3½	6	175	270
4	6		500
4	7	250	
4	8	300	550
4½	10	400	750
5	6		650
5	10	500	900
5½	12	650	
6	10		1400
6	12	850	1500
7	10		1850
7	12	1200	2200
8	12	1400	2700
8½	12	1800	3000
9	12		3200
10	12		4000
10	16	2500	
10	18	2600	
10	20	2700	
12	15		5200
12	20	3750	

In the diagram, tracing lines have been drawn starting with a pump 6 in. in diameter, 12 in. stroke, making 50 strokes per minute, having a 10 per cent slip, pumping against a head of 250 ft., with efficiency of 50 per cent and a steam consumption per indicated horsepower

of 60 lb. The dotted line continuations in each case show the readings for displacement per stroke, displacement per minute, water per minute, etc. To read the total steam per hour direct from the water horsepower, pass from the intersection with the diagonal for the head to the left to 100 per cent efficiency line, then downward from that to the diagonal representing the proper steam consumption per horsepower-hour, and then

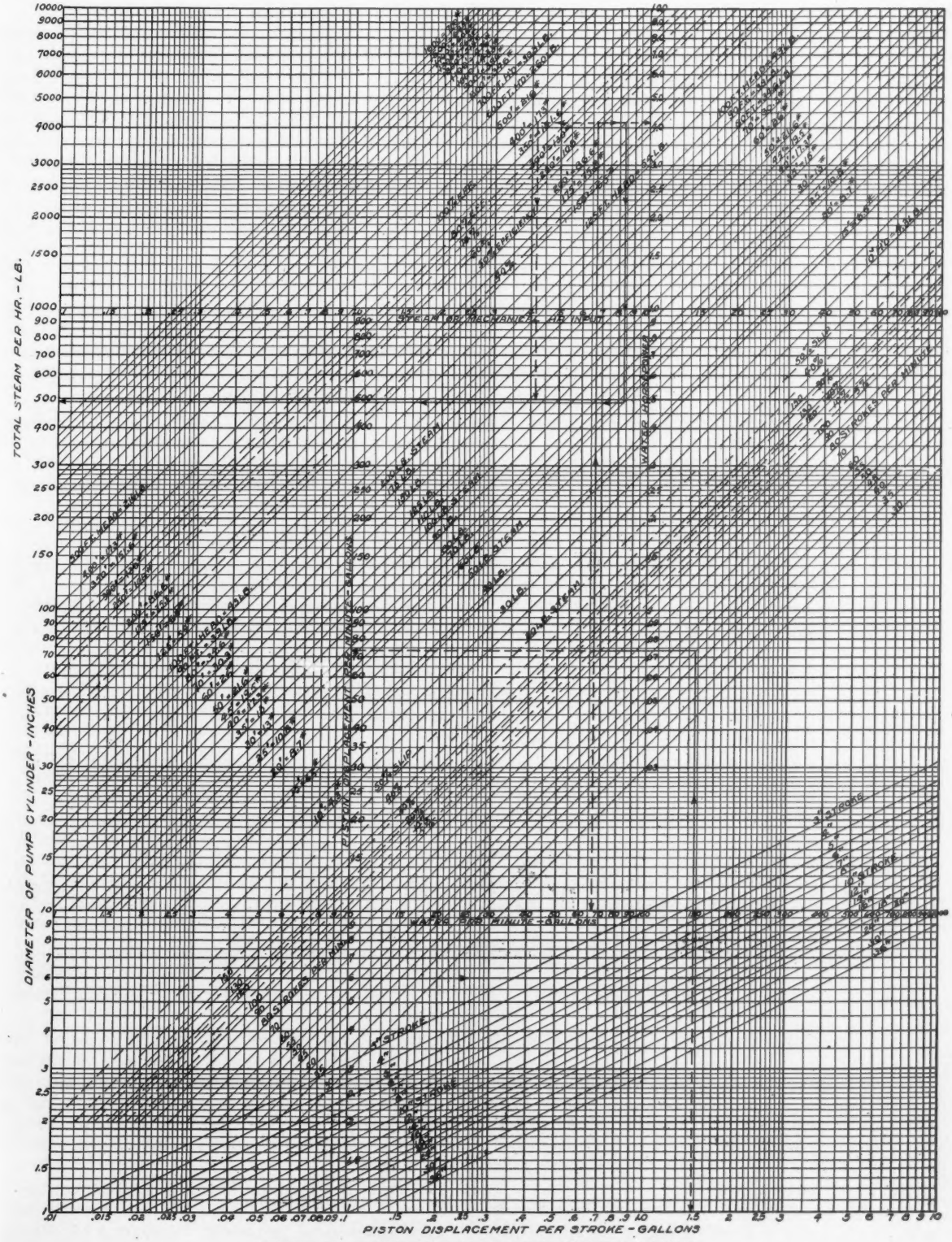

TOTAL STEAM PER HR. - LB.
DIAMETER OF PUMP CYLINDER - INCHES
PISTON DISPLACEMENT PER STROKE - GALLONS
STEAM PER MECHANICAL HP IN HR.
WATER PER MINUTE - GALLONS
STROKES PER MINUTE

CHART OF PERFORMANCE FOR RECIPROCATING PUMPS

to the left, reading the total steam per hour on the left hand axis. Of course with a 50 per cent efficiency and the same rate of steam consumption the steam per water horsepower per hour would be 120 lb., and the total steam consumption would be the same as if traced through the 50 per cent efficiency line, and the 60-lb. steam per mechanical horsepower-hour diagonal.

Energy Losses

Taking up in detail the losses which occur in the pump, these are due to slip already explained, to mechanical friction, loss of head through valves, friction in pipes, the entrance and discharge heads and velocity head. The velocity head is that required to set the liquid in motion and varies as the square of the velocity. The velocity head required for different velocities of flow in a pumping system is as follows:

ing. The spring pressure should be such that it is not over 1 per cent of the discharge pressure, and with valves properly designed according to the rules under valve details the friction through the seats may be neglected. In this case the total loss on the discharge end would be 1 per cent of the discharge head.

The other loss to be taken care of is the friction head in pipes and fittings, which varies with the size of pipe and the velocity of flow according to a complicated set of laws which cannot well be expressed in any simple formula or rule. It seems wise, therefore, to give Table IX, published by the Fairbanks-Morse Co., the relations between the velocity in feet per second, the amount of flow, for different sizes of pipes, and the friction loss in feet head per 100 ft. length of clean pipe. For the friction loss in elbows, Nickel gives: For a long radius bend

Values of Velocity and Velocity Head

Velocity in Ft. per Sec.	2	3	4	5	6	7	8	9	10	12	16	20
Velocity Head, Ft......	0.062	0.140	0.248	0.389	0.560	0.762	0.995	1.259	1.55	2.24	3.98	6.22

TABLE IX. FRICTION LOSS IN PIPES 100 FT. LONG AT VARIOUS VELOCITIES OF FLOW

Velocity	¾ In. Pipe Capacity	¾ In. Pipe Friction	1 In. Pipe Capacity	1 In. Pipe Friction	1¼ In. Pipe Capacity	1¼ In. Pipe Friction	1½ In. Pipe Capacity	1½ In. Pipe Friction	2 In. Pipe Capacity	2 In. Pipe Friction	2½ In. Pipe Capacity	2½ In. Pipe Friction	3 In. Pipe Capacity	3 In. Pipe Friction	4 In. Pipe Capacity	4 In. Pipe Friction	5 In. Pipe Capacity	5 In. Pipe Friction	Velocity
3	4.03	5.98	7.31	4.08	11.6	3.91	16.5	2.7	29.4	2.04	47.2	1.71	66	1.36	117	1.02	184	.82	3
4	5.50	10.49	9.82	6.83	15.1	5.79	22.0	4.5	39.2	3.4	61.0	2.6	81	2.28	156	1.71	245	1.67	4
5	6.89	13.64	12.24	10.25	19.4	8.32	27.4	6.8	48.9	5.1	76.5	4.1	110	3.4	196	2.56	306	2.05	5
6	8.25	19.12	14.68	14.33	23.2	12.34	32.9	9.5	58.7	7.2	91.8	5.7	132	4.7	236	3.6	367	2.87	6
7	9.65	25.44	17.13	19.08	26.8	16.56	34.4	12.7	68.5	9.5	107	7.6	154	6.3	275	4.8	428	3.8	7
8	11.01	32.64	19.58	24.50	30.3	20.82	43.8	16.3	78.3	12.2	122	9.8	176	8.1	314	6.1	490	4.9	8
8½	11.70	36.60	20.80	27 46	32.5	23.65	46.6	18.3	83.2	13.7	130	10.9	187	9.1	334	6.9	521	5.5	8½
9	12.39	40.40	22.03	30.58	34.5	25.51	49.4	20.4	88.1	15.2	138	12.2	198	10.1	352	7.6	551	6.1	9
9½	13.08	44.80	23.25	33.88	36.3	28.34	52.2	22.5	93.6	16.9	145	13.5	209	11.2	372	8.5	581	6.7	9½
10	13.79	49.68	24.48	37.33	38.3	30.53	55.3	24.9	97.9	18.6	153	14.9	220	12.4	391	9.3	612	7.5	10
10½	14.45	54.40	25.70	40.06	40.1	33.56	57.7	27.3	103	20.4	161	16.3	231	13.6	411	10.2	642	8.2	10½
11	15.15	59.60	26.92	44.75	42.6	36.41	60.5	29.8	108	22.3	168	17.9	242	14.9	431	11.1	673	8.9	11
11½	15.85	64.80	28.15	48.71	44.6	40.12	63.2	32.5	113	24.3	176	19.5	253	16.2	450	12.1	704	9.7	11½
12	16.52	70.40	29.37	52.83	46.8	43.73	66.6	35.2	117	26.4	184	21.0	264	17.6	471	13.2	735	10.6	12
13	17.94	82.00	31.82	31.58	49.5	49.91	71.5	41.0	127	30.7	199	24.6	286	20.5	510	15.3	796	12.3	13
14	19.30	94.80	34.27	71.00	53.5	57.25	77.8	47.3	139	35.5	214	28.4	308	23.7	549	17.7	857	14.2	14
15	20.75	108.00	36.72	81.08	57.4	64.82	82.5	54.0	149	40.5	230	32.4	330	27.0	587	20.3	918	16.2	15

Velocity	6 In. Pipe Capacity	6 In. Pipe Friction	7 In. Pipe Capacity	7 In. Pipe Friction	8 In. Pipe Capacity	8 In. Pipe Friction	10 In. Pipe Capacity	10 In. Pipe Friction	12 In. Pipe Capacity	12 In. Pipe Friction	15 In. Pipe Capacity	15 In. Pipe Friction	18 In. Pipe Capacity	18 In. Pipe Friction	20 In. Pipe Capacity	20 In. Pipe Friction	24 In. Pipe Capacity	24 In. Pipe Friction	Velocity
3	264	68	360	.58	470	.51	734	.41	1058	.34	1652	.27	2379	.23	2938	.20	4230	.17	3
4	353	1.14	470	.98	627	.85	979	.68	1410	.57	2203	.46	3173	.38	3917	.34	5640	.28	4
5	440	1.70	600	1 46	783	1.28	1224	1.02	1763	.87	2755	.68	3965	.57	4896	.51	7051	.43	5
6	528	2.38	720	2.05	940	1.79	1468	1.43	2115	1.21	3304	.96	4758	.80	5875	.72	8461	60	6
7	617	3.18	840	2 72	1097	2.38	1713	1.90	2468	1.62	3855	1.27	5552	1.06	6854	.95	9870	.79	7
8	706	4.08	959	3.49	1253	3.06	1958	2.45	2820	2.08	4407	1.63	6345	1.36	7833	1.22	11280	1.01	8
8½	749	4.57	1019	3.92	1331	3.43	2081	2.74	2996	2.33	4688	1.82	6742	1.52	8323	1.37	11985	1.14	8½
9	794	5.09	1079	4.36	1410	3.82	2203	3.05	3173	2.60	4958	2.04	7138	1.70	8812	1.53	12690	1.27	9
9½	837	5.61	1139	4.83	1488	4.23	2326	3 38	3349	2.88	5232	2.25	7535	1.88	9302	1 69	13395	1.40	9½
10	882	6.21	1199	5.33	1567	4.66	2448	3.73	3525	3.17	5508	2.50	7931	2.07	9792	1.87	14100	1.55	10
10½	925	6.82	1259	5.84	1646	5.22	2571	4.09	3701	3.48	5783	2.73	8329	2.27	10281	2.05	14805	1.70	10½
11	970	7.45	1319	6.39	1723	5.59	2693	4.47	3878	3.80	6058	2.98	8725	2.48	10771	2.24	15510	1.86	11
11½	1013	8.11	1379	6.95	1801	6.08	2815	4.87	4054	4.14	6335	3.25	9122	2.70	11258	2.43	16215	2.03	11½
12	1058	8.80	1439	7.54	1880	6 60	2938	5.28	4230	4.49	6610	3.52	9518	2.93	11750	2.64	16920	2.20	12
13	1145	10.26	1559	8.74	2037	7.90	3182	6.15	4583	5.23	7161	4.10	10310	3.42	12729	3.08	18330	2.56	13
14	1233	11.83	1679	10.14	2193	8.87	3472	7 10	4935	6.03	7711	4.73	11104	3.93	13708	3.55	19740	2.95	14
15	1321	13.51	1799	11.58	2350	10.01	3672	8.10	5288	6.89	8262	5.40	11897	4.50	14688	4.05	21150	3.37	15

Velocity	30 In. Pipe Capacity	30 In. Pipe Friction	32 In. Pipe Capacity	32 In. Pipe Friction	36 In. Pipe Capacity	36 In. Pipe Friction	42 In. Pipe Capacity	42 In. Pipe Friction	45 In. Pipe Capacity	45 In. Pipe Friction	48 In. Pipe Capacity	48 In. Pipe Friction	54 In. Pipe Capacity	54 In. Pipe Friction	60 In. Pipe Capacity	60 In. Pipe Friction	72 In. Pipe Capacity	72 In. Pipe Friction	Velocity
3	6610	.136	7520	.128	9518	.113	12955	097	14872	.091	16921	085	21415	.076	26438	.068	30871	.057	3
4	8813	.228	10027	.214	12690	.190	17273	.163	19829	.152	22561	.145	28553	.127	35251	.114	50762	.095	4
5	11015	.341	12534	.320	15863	.284	21591	.244	24786	.228	28201	.214	35692	.190	44064	.171	63452	.142	5
6	13218	.478	15040	.448	19036	.397	25910	.341	29743	.319	33845	.299	42830	.265	52877	.239	76142	.199	6
7	15421	.636	17547	.596	22208	.528	30228	.454	34700	.424	39481	.398	49968	.353	61689	.318	88833	.265	7
8	17624	.816	20054	.765	25381	.679	34546	.583	39657	.544	45121	.510	57107	.454	70502	.408	101523	.340	8
8½	18725	.915	21307	.858	26967	.760	36705	.654	42136	.610	47941	.572	60676	.508	74909	.458	107868	.381	8½
9	19827	1.01	22561	.956	28554	.847	38864	.728	44615	.680	50762	.637	64245	.566	79315	.510	114214	.425	9
9½	20928	1.12	23814	1.06	30140	.938	41023	.807	47093	.753	53582	.706	67814	.627	83721	.565	120559	.470	9½
10	22030	1.24	25067	1.17	31726	1.03	43183	.899	49572	.830	56402	.778	71383	.691	88128	.622	126904	.519	10
10½	23131	1.36	26321	1.28	33313	1.13	45342	.975	52050	.910	59222	.853	74953	.758	92534	.683	133249	.569	10½
11	24233	1.49	27574	1.40	34899	1.16	47501	1.07	54529	.994	62042	.932	78522	.829	96941	.746	139594	.622	11
11½	25338	1.62	28828	1.52	36485	1.35	49660	1.16	57208	1.08	64862	1.02	82091	.902	101347	.812	145940	.677	11½
12	26436	1.76	30081	1.65	38072	1.46	51819	1.26	59486	1.17	67682	1.10	85660	.978	105753	.881	152285	.734	12
13	28639	2.05	32588	1.92	41214	1.70	56137	1.47	64443	1.37	73322	1.28	92798	1.14	114566	1.03	164975	.855	13
14	30842	2.37	35094	2.22	44417	1.97	60456	1.69	69408	1.58	78962	1.48	99937	1.32	123379	1.18	177666	.986	14
15	33045	2.70	37601	2.53	46590	2.24	64774	1.93	74358	1.80	84603	1.69	107075	1.50	132192	1.35	190356	1.23	15

A common suction velocity is 3 ft. a second, or 180 ft. a minute.

Entrance head, that is, the head used up in forcing the water into the end of the suction pipe, varies as the velocity and the shape of the entrance opening. Nickel states that for a square end it will be half the velocity head; for a funnel end, zero; and for a strainer it will be equal to the velocity head.

Discharge head varies as the resistance at the discharge valve, which is proportional to the spring pressure, and the pressure against which the pump is working.

the loss in head for each bend is ¼ the velocity head. For a bend with radius equal to the diameter of the pipe, the loss for each elbow will be ½ the velocity head; and for a sharp bend the loss at each elbow will equal the velocity head, which means practically that the water is stopped in one direction and started in a direction at right angles.

In order to show the effect of a long suction pipe on the action of the pump, the total suction resistance is here determined for two cases. First, for a 1½-in. pipe, 20 ft. long, having 2 medium radius bends, and the

water flowing at 3 ft. per second. Second, for a similar pipe with the same velocity of flow, but 200 ft. in length and having 3 bends. In the first case the velocity head as shown by the table above at 3 ft. per second is 0.14 ft.

For a medium radius bend the loss is half the velocity head for each, or for 2 bends equal to the velocity head, or 0.14 ft. The entrance loss for a square ended pipe is half the velocity head, or 0.07 ft. From Table IX the friction head loss at 3 ft. per second will be about 2.7 ft. per 100 ft. of pipe, and for 20 ft. one-fifth of that, or 0.54 ft. Then for the total head loss in the suction system the sum of these values is 0.89 ft.

For the second case, the velocity head will be the same, the entrance head the same. For the 3 bends we shall have 1½ times the velocity head, or 0.21 ft., and the pipe friction loss will be 10 times as great, or 5.4 ft., the total loss being 5.82 ft. in the suction system, so that the possible suction lift would be reduced accordingly on account of the extra 180 ft. length of suction pipe and the extra bend.

While the loss through the suction valve will vary according to the strength of spring used, with springs as ordinarily designed it will be about ½ lb. per square inch, or 1.15 ft. of head. The velocity through the valve is usually taken at 250 ft. a minute, for the suction pipe in smaller sizes at about 180 to 200 ft. a minute, and in the discharge pipe at about 300 ft. a minute.

Pump Speed and Capacity

Evidently the capacity of a pump cylinder is determined by the piston speed at which it works, and in older practice 100 ft. a minute piston speed was taken as a standard. In a small pump, however, say 3 in. stroke, this requires 400 strokes a minute, which is altogether too fast to allow good seating of the valves. The chart herewith shows the relation between the stroke in inches, the strokes per minute and the piston speed in feet per minute, and the cross lines indicate the usual piston speed at which pumps are run for different purposes. For long strokes higher piston speed may be used satisfactorily on account of the lessened number of reversals and the greater time allowed for the seating of the valves. Because of the small amount of water handled a vacuum pump can usually be run faster than a boiler feed.

As indicated on the diagram, in medium sizes pumps are usually at their best at from 60 to 80 strokes per minute, but in the smaller sizes they run up to 100 strokes or even higher.

One effect of high speed in pumps is that for rapid reversal, heavy springs must be used on the valves, and the valves must be given low lift. This is directly opposed to the requirements for good efficiency which call for a high lift and a large passage for the water, and also for a light spring in order to cut down the friction through the valves. The slower speed of the pump permits of the use of a lighter spring, and a somewhat higher lift, although the lift requirement is usually taken care of by using a large number of small valves but at increased cost of the pump. Another objection to rapid reversal is the great wear on the valves and seats, and the liability to breakage in the case of composition disks.

Particularly in a case where there is a long column in water, either in suction or discharge, rapid reversal is difficult because of the inertia of the water column and rapid running is apt to produce water hammer, which may be disastrous to the fittings.

Air Chambers

To overcome this somewhat, air chambers may be used to lessen the shock, the size depending on the speed and the length of the column of water. For ordinary boiler feed and service pumps the volume of the air chamber is made 2 to 3 times the piston displacement of the pump, for a single cylinder pump, and 1 to 2

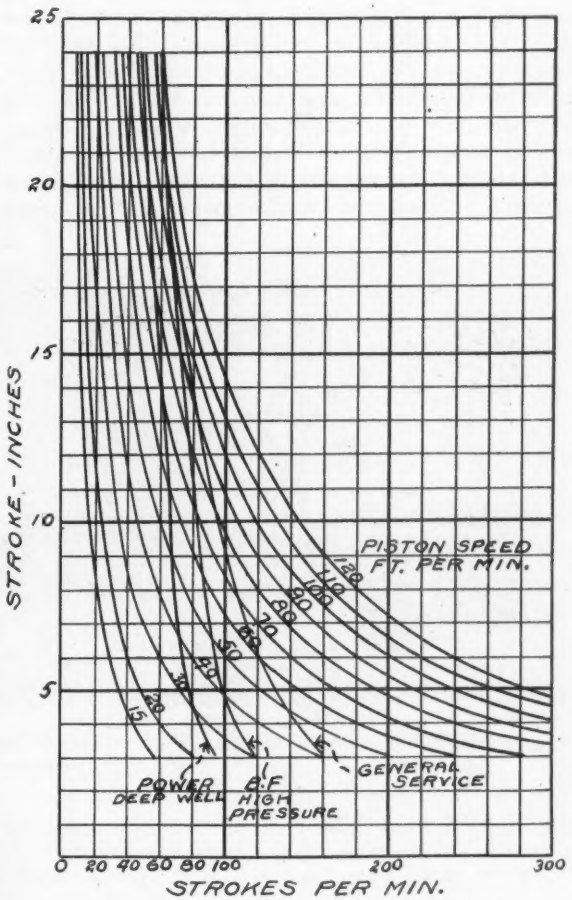


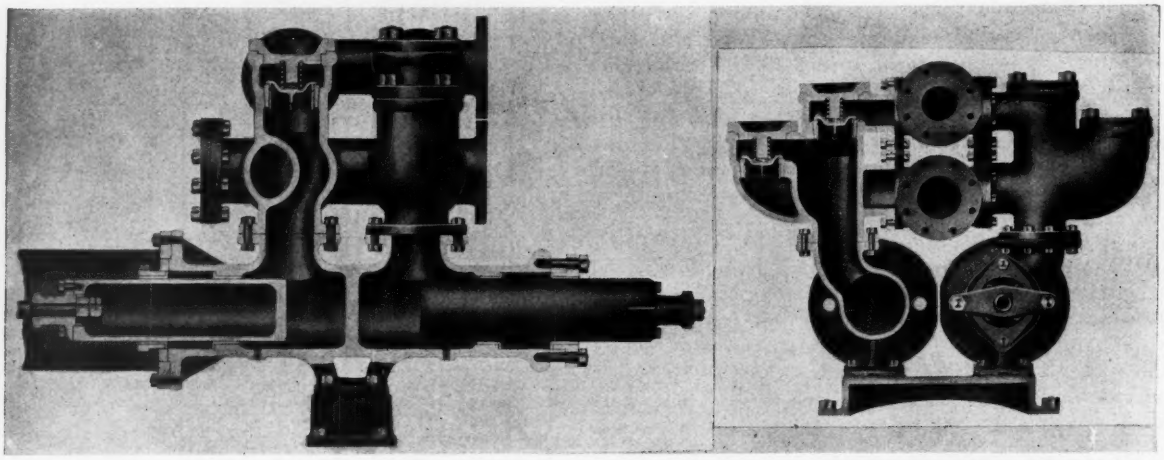
CHART OF PUMP STROKE AND PISTON SPEED

times the piston displacement for a duplex. Where a high piston speed is to be used as in fire pumps, the volume of the air chamber should be made 6 times the piston displacement.

The discharge air chamber should be mounted at the highest point of the valve chest and above the delivery opening in order to hold the air, and must be provided with some means of renewing the air, as this will be rapidly absorbed by the water, particularly at pressures above 300 lb. per square inch. While the air chamber is useful when applied to the discharge system, air pockets in the pump chambers must be avoided, in either suction or discharge end, as they will cause a churning back and forth without flow of water due to the compression and expansion of the air in these pockets, as the piston moves back and forth. This is known as air binding and seriously reduces the capacity of the pump.

Valve Decks

VALVE DECKS of a pump are arranged in one of 3 ways, with both decks overhead, with the suction and discharge decks side by side, or with the discharge valves above and the suction valves below the cylinder. The first arrangement is convenient to get at and is compact, but calls for the reversal of flow of the water in the passages of the pump. The second arrangement is also convenient to get at, but occupies more space and makes a more difficult design to manufacture. Frequently this is used with small chambers in the pot valve type of pump for high pressures. The third arrangement requires more space as there must be room below the cylinder for a valve deck as well as above, but the water moves straight through the pump passages without reversal and the suction valves are so placed that they are always covered with water. This water sealing is of benefit in vacuum pumps and in pumps handling hot water. There is, however, the possibility with this arrangement, if the suction valves leak, of losing the water from the barrel of the pump, and in this case it will be necessary to prime the pump before it will be possible to start. The first arrangement is the most commonly used for small pumps and for low pressures. The second for high pressure or hydraulic pumps, and the third for large pumps and for heavy liquors.



CONSTRUCTION OF POT VALVE TYPE OF PUMP END OF H. R. WORTHINGTON. SIDE BY SIDE VALVE DECKS AND HOLLOW OUTSIDE END PACKED PLUNGERS

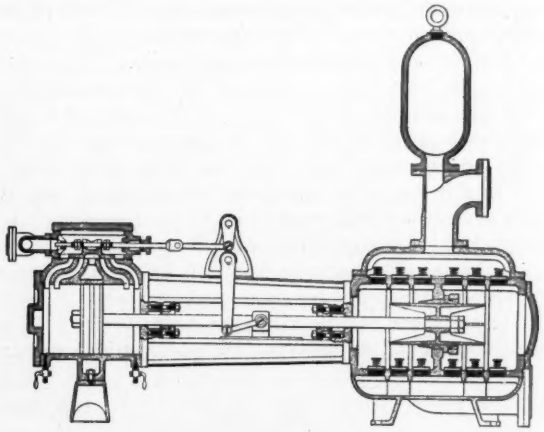
For the sake of compactness it is desirable to keep the valves as near together as possible, but the metal between the seats must have strength to carry the pressure, and 1¼ in. between the seats of 4 in. valves is found as close as is ordinarily desirable. If, however, a closer arrangement is necessary, it is possible to secure extra strength by ribbing the deck below the level of the bottom of the valve seat, although this complicates the structure of the pump and somewhat reduces the area of the water passages.

Valve Lift and Diameter

As already indicated, the design of a pump valve is a compromise, since quick action demands a light valve with a stiff spring, a small lift and a small valve, while small water friction demands a conical seat to give straight passage to the water, a large diameter which requires a heavy valve, and a high lift in order to give large valve opening. The compromise usually takes the form of using several small valves with a small lift, a fairly stiff spring in order to get quick closing, and a flat seat rather than a conical, in order to reduce the amount of lift. To give an area between valve and seat equal to the area through the valve opening would require a lift equal to ¼ the diameter of the valve, but this is obviously too high. Usually sufficient valve opening is required to give a combined area for low speed pumps of 30 per cent of piston area and for high speeds 50 per cent. The maximum diameter of valves found advisable is 4 in., and a 3 in. maximum diameter is better. The small diameter gives a small lift in order to get full opening, reduces the slip, reduces the wear on the valve and reduces the spring tension necessary to seat the valve.

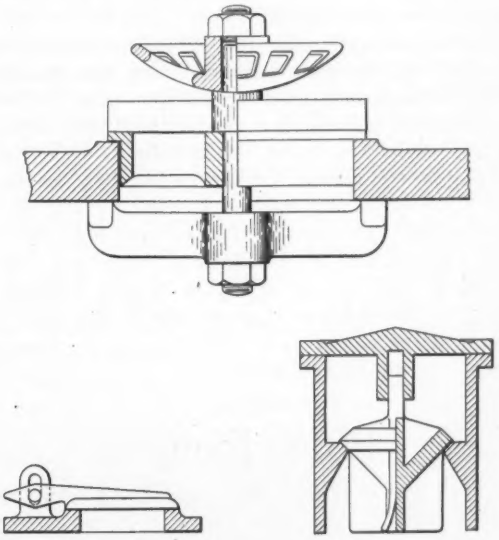
The seat is usually screwed or forced into the deck, is tapered and carries the valve, which is held to the seat by a bolt into the bridge across the seat or by a stem coming through the valve and held down by a cap in the valve chest cover. The valves are of various types, the earliest being the flexible valve, which was made 3 to 4 in. in diameter for low heads with a grid or stop piece to prevent its rising too high. The types of valves now in common use are the clapper valves, used in mine and pit pumps where there is much gravel or other dirt in the water so that a clear opening is required; the ball valve used in the same way, also for the bucket type of deep well and mine pump, and also for pumps where heavy liquors such as tar or molasses are to be handled; and the disk valve, which is of poppet type, rising straight from a flat seat. In the clapper valve the lift should be ⅛ to ¼ in. before the valve starts to swing, and the valve should then swing open against a stop at an angle of 30 to 60 deg. Ball valves are usually hollow, of bronze, and have a diameter 1⅓ times the diameter of the seat, which is raised to allow a pocket for collecting dirt and sediment. The conical wing valve

has a 45 deg. seat and a 45 deg. lower surface to the valve, but requires a lift of 40 per cent more than the flat valve to give a like area of opening. One advantage of this type, which is usually seated by its own weight, is that by placing inclined wings on the bottom the valve can be caused to rotate and thus change its seating at each stroke. It is a good valve for slow work, for heavy liquor or for dirty water. If a guide is used with a conical valve it should be in the seat, and if inclined wings are used, the angle is usually made ½ in. for 6 in. of length.



PLUNGER AND RING PUMP OF BUFFALO STEAM PUMP CO. WITH SUBMERGED SUCTION VALVES

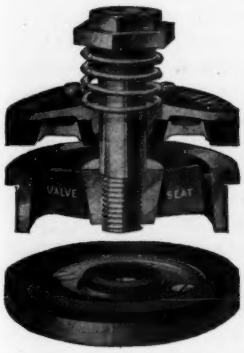
In the disk valve the lift most commonly used is ¼ in., regardless of the diameter of the valve. The seat is made of bronze or gun metal with ribs to form a bridge which carries the center stud, the stud being preferable to the bolt as it will hold the valve true to the seat while the bolt carried by the steam chest cover may cause the valve to bind. The disk of the valve is usually made of rubber, a soft quality for vacuum and medium pressures up to 75 lb., a hard rubber for 75 to 150 lb., specially hard vulcanized up to 300 lb., and above this pressure metal disks. For hot water, metal is usually used for all pressures as composition has a short life under such conditions. Common practice now provides a metal cap to fit over the disk in order to keep it from warping, also to take the pressure of the spring. An advantage in using the composition disk is that both faces may be used, the disk being turned when one face is worn. Also the disk is easily replaced and at slight expense. Where metal disks are used the seat and valve should be of the same metal in order to avoid galvanic action. Many special designs of valves have been found to give good results, some of them using the metal disk of ring form with the face carrying bearing surfaces of the composition proper for the service to which the pump is to be adapted.



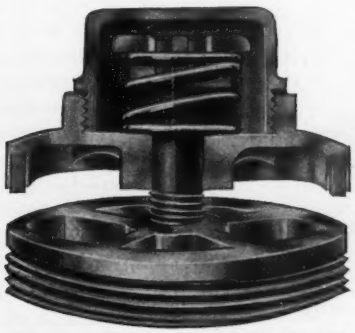
1. FLEXIBLE RUBBER VALVE WITH GUARD
2. CLAPPER VALVE WITH LIFT AND STOP
3. CONICAL VALVE; LEFT HALF SHOWS INCLINED WING; RIGHT HALF STRAIGHT WING

In determining the area for the valve seat, the bearing area is usually made 50 per cent of the free seat opening, the pressures between valve disk and seat which may well be used being as follows: For rubber, 125 lb. per square inch; for leather, 250 lb.; for cast iron, 350 lb.; for gun metal, 700 lb.; bronze, 1000 lb.; and for steel, 4000 lb.

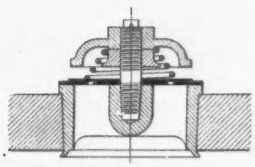
The area for clapper valves is made in proportion to the piston speed. For 100 ft. a minute or less the valve area is made 40 per cent of the plunger area.



HILL PUMP VALVE CO.



IDEAL VALVE OF LAKE ERIE MFG. CO.



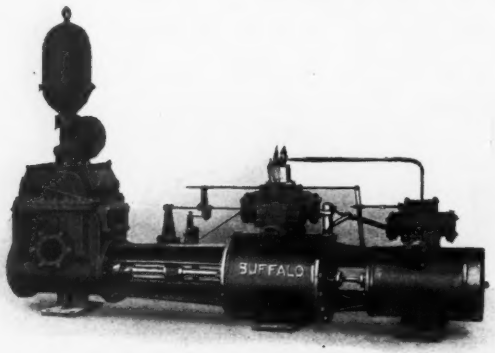
KINGHORN MULTIPLE DISK VALVE

For 125 ft., 50 per cent; 150 ft., 60 per cent; 175 ft., 75 per cent, and 200 ft., 100 per cent. For disk valves closed by springs, the combined area of valve seat openings is usually made 50 per cent of the piston area, with the spring pressure on the discharge valves equal to ½ to 1 per cent of the discharge pressure, the maximum being 5 lb. per square inch.

For the springs to close the valves, preferably 5 coils are used with the coils parallel, brass wire being the material chosen and of approximately the following sizes, although this varies somewhat with the temper of the wire. For a 2-in. valve, No. 12 Brown & Sharp gage; for 3 and 3½-in. valves, No. 10; for 4 and 4½-in. valves, No. 8. A cap should properly be used to hold the top of the spring, and this should be screwed onto the stud, with a cotter pin to prevent it from unscrewing. In the valve deck sufficient room should be left between the valves and the walls, so that the area at this point will equal the area of the valve opening and the discharge passage will not be restricted.

Piston Pumps

IN THE piston pumps valves should be easily accessible, either by removing the chest cover, or by taking off handhole covers; in many pumps the suction valves are arranged directly under the discharge valves, which is convenient both for examination and in the replacing or regrinding of seats. The pump should be so arranged that stuffing boxes or pistons may be easily repacked and cylinders relined if necessary. The frame or body of the pump, which holds all parts together and each separately in position, should have sufficient iron to be massive, yet distributed to be of the greatest use. Standards or legs should be of good length so that the

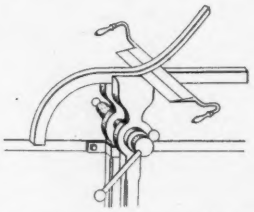


PISTON PUMP OF BUFFALO STEAM PUMP CO. TO SHOW FRAME CONSTRUCTION FOR COMPOUND TANDEM ARRANGEMENT

pump may stand well away from the foundation and be accessible, the feet having large surface to secure stability and good bearing. For smaller sizes the frame is often cast in one piece with the inner cylinder head and in the larger sizes it has brackets which bolt to the cylinder heads, either on 2 sides or at the bottom. For some types rods join the steam and water ends, an arrangement which gives facility in repairs and renewals and also gives free access to the glands and rods.

Pistons

THE piston is usually made in 2 parts, a body and follower, connected in the smaller sizes by a nut on the piston rod, and in the larger sizes by follower bolts and nuts. A space is provided on the outside of the piston for fibrous packing rings, 4 rings ¾ in. square packing being usually used for cold water and thin liquors. For vacuum and low-pressure pumps, water grooves in the outside of the piston are frequently used and have the advantage of requiring no repacking. For hot liquids and where the liquors handled must be kept clean, snap rings are used inserted in grooves in a solid cast piston. In deep well pumps a leather cup packing is frequently used for the buckets and gives good service. This packing is made by pressing sheets of wet leather into iron forms and allowing them to dry, after which the edges are finished beveled. For the fibrous packing the rings should be cut from ⅛ to 3/16 in. short of meeting in order to give room for expansion, and should fit into the recess moderately finger tight and fit the bore snug when first packed. Usually this packing is made so that layers may be peeled off to get proper width, but it is important that the depth should be right, and in case it is necessary to cut down the packing, the method shown in the accompanying figure, gripping the packing in a vise and



METHOD OF CUTTING DOWN DEPTH OF PISTON PACKING

cutting it with a draw knife will be found convenient and accurate. The piston is packed the same as a stuffing box, the rings, arranged so as to break joints, being put in with a stick of soft wood and forced home. Coating the packing with cylinder oil and graphite will be found to give good joints, easy action and easy removal. It is well to keep a few rings of packing on hand ready cut so that when examining a piston new rings may be inserted if necessary for a quick repair and to soak the packing a few hours in hot water just before inserting. For snap rings the ring should usually be turned in the solid about ⅛ in. larger than the piston for a 12-in. piston, and other sizes in proportion; the ring is then split on a 45-deg. diagonal, squeezed together and a light finish chip, or better, a light grinding cut taken off to bring to size.

Rods and Stuffing Boxes

USUALLY the piston is held on the rod by a neck and shoulder, or by a tapered fit or by a combination of the two, and the follower should be held by a fine-thread nut with a ¼-in. lock pin put through the rod behind the nut to prevent backing off.

The piston rod is made larger than would be necessary for the force to be carried in order to avoid vibration and deflection. The sizes of cold rolled steel rods of a tensile strength of 65,000, and a factor of safety of 10 for 150 lb. water pressure on the pump end being

approximately as shown in the table herewith, which also shows the size of the piston fit for a straight neck and the thread to be used for the lock nut. For rods having the piston fit under 1 in. in diameter the U. S. standard thread may well be used.

Piston Diam. In.	Rod Diam. In.	Piston Fit, In.	Threads per In.	Valve Rod Diam. In.
4	1⅜	1⅛	8	⅜
6	1⅝	1⅜	8	½
8	1⅞	1½	8	⅝
10	2¼	1¾	8	¾
12	2⅜	1¾	8	⅞
14	2½	2	8	⅞

Stuffing boxes for rods up to 1 in. diameter are usually screwed into the cylinder head and have a gland with cap screwing on the outside of the stuffing box. For larger cylinders the stuffing box is cast with the head, has the inner end bushed and on the outside end a gland held in place by stud bolts and nuts. Two bolts are always preferable to 4, as the pressure can be kept equalized better in this way. The stuffing box should be of a depth to take 6 rings of packing, and for high vacuum pumps is usually provided with a water seal in the center to prevent inleakage of air. The piston type of pump has the advantage of being inexpensive, having a short, compact water end and taking up little floor space. It is not adapted, however, to very high pressures and must be taken down in order to repack the piston.

Cylinders

Cylinders of such pumps are usually made with a lining which is either forced in or is held in place by stud bolts at the end, the latter construction being preferable in large size pumps on account of the difficulty of taking out and renewing the liner. For low pressure pumps and where cheapness is the first consideration, the cylinder may be made a bored casting with provision of metal for reboring in case of scoring of the cylinder walls.

Clearance in the pump cylinder is not a source of loss as in the steam cylinder, hence it is desirable to have a generous amount to provide a place for grit or foreign matter to settle and to avoid chance of the pump piston striking the cylinder head. In the steam end, however, the clearance should be kept as small as possible, as added clearance means waste of steam. Ports and passages for the water should be large enough so that the velocity with the pump working at its greatest speed will not exceed 300 ft. a minute, and for ordinary speeds should not be over 250 ft. Ports should be made as short and direct as possible, and so arranged that the water in passing into, through and away from the pump will change its direction as little as possible, but this last condition usually conflicts with the placing of valves so that they may be readily accessible.

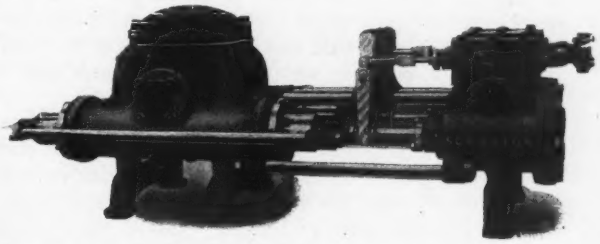
Details of construction are illustrated in the various views of commercial pumps.

Forms should not be removed from concrete work until it is strong, the time varies with climatic conditions. For concrete that has not been frozen the test is a blow with a hammer, if a good ringing sound results the work will generally be hard and strong enough to remove the forms.

Plunger Pumps

Plungers are made of 3 types, the hollow open plunger, such as is used for inside packed pumps either of the plunger and ring type or of the packed plunger type; hollow plungers with closed ends usually used for the outside packed type, either center packed or end packed, and the solid plungers or rams used particularly for high pressure work. In the plunger and ring type no packing is used, the plunger being made a close fit with a metal ring, this ring being held in the center of the cylinder by stud bolts, and replaceable. The ring is made of bronze, so that any scoring will be on the ring rather than the cast-iron plunger, as this is the less expensive method of repair, and 0.001 in. difference in diameter is allowed. This type has the advantage over the piston pump that the ring is cheaper to replace than the cylinder lining, but it must be taken down in order to replace the ring. It is not a type adapted for dirty water or where there is likelihood of frequent scoring of the ring or plunger.

If the water is gritty, or where conditions are such that the joint between plunger and ring is likely to be difficult to keep tight, a packed ring is provided, consisting of a body with a follower and space between the 2 for fibrous packing rings similar to those used in packing the piston type. The advantage of the fibrous packed plunger over the packed piston is that in case of scoring it is cheaper to replace the plunger than to replace a cylinder lining.



OUTSIDE END PACKED PUMP OF THE SCRANTON PUMP CO.

Inside-packed punger pumps are longer than the piston type since the cylinder must have length not only for the stroke, but also for the length of the plunger, which must be equal to the stroke plus the length of the center ring. The longer the ring the better will be the joint between it and the plunger. It is ordinarily made from ½ to ⅔ the length of the stroke, giving a plunger length of 1½ to 1⅔ stroke. This lengthening of the cylinder means longer ports in the steam end and a very large clearance in the water end, which tends to increase the chance for slip through the water valves.

Outside Packed Plungers

In the outside packed plunger pump with center packing, the single plunger runs through 2 stuffing boxes at the center, each of which is accessible without taking down the pump, and a stuffing box for the plunger rod is also provided at the inside end of the inner cylinder. This is, in effect, 2 single acting plunger cylinders, and frequently is arranged with separate valve chests for each end of the pump. Evidently it requires a long water end casting, but has the advantage of only

one piston rod and leakage around the plunger can be seen and remedied while the pump is working. For very high pressures it has the disadvantage that it is difficult to keep the stuffing box on the rod tight without undue friction.

For the outside packed plunger type with end packing, stuffing boxes are provided at each end of the pump cylinder, and a center partition is inserted in the cylinder, usually being a plate bolted to an inside ring flange. The two plungers are joined by side rods which are connected by crossheads, the inner crosshead being driven direct by the piston rod from the steam end. This permits of a short, compact water end, is easy to repack and keep tight while in operation and is suitable for the highest pressures. In this type the steam and water ends are often joined by rods keyed into sockets in the cylinder casting.

Types of Fittings

Pump ends are made on 4 general specifications, according to the purposes for which they are to be used. In the all iron pump the valve-seats are malleable iron, the springs of steel, the cylinder bore not lined, and the rod nuts of iron. This type is used for such liquids as ammonia, tar, caustic soda and milk of lime, where brass or bronze is affected by the material handled and is therefore not permissible. The regular fitted pump has the piston or plunger of cast iron, the piston rod of steel, the cylinder bronze lined, and the valve-seats, springs and nuts of bronze. The valves are of material suitable for the purpose of the pump as explained under the subject of valves and valve decks. This is the pump as ordinarily used for water and other liquids not requiring special treatment.

The third class or bronze fitted pump has the piston of bronze or bronze lined, the piston rod of bronze, stuffing box and glands bronze or bronze lined, the cylinder with bronze lining, the valve-seats and nuts of bronze, and usually the valves of bronze. This is used for tan liquor, beer or brine, oil, salt water or sewage, or for other purpose where iron or steel would be affected by the liquid handled.

The all bronze pump is made with all parts of bronze, no iron or steel being used, and is for handling such liquids as will attack iron or steel but do not attack bronze.

For special purposes, where the pumps must be carefully protected from all action of acids or similar liquors, a lead or wood lining may be used, all surfaces being covered by either the lead or wood. Such a lining may also be used where it is particularly desired that the liquid handled shall be protected from any possible taste due to contact with a metal, such as in the handling of vinegar, whiskey or milk.

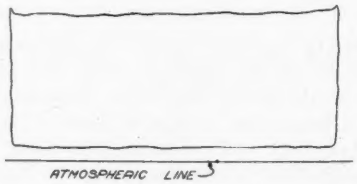
The Executive Committee of the National Gas Engine Association has selected Chicago as the city in which the Eighth Annual Meeting will be held during the week of June 25, 1916. The officers are at work preparing a program which promises to be a most interesting one. The standardization committee will make its report at this meeting recommending for adoption several important changes in the industry, which are thought to be of advantage to members of the association.

Steam Pumps

In direct-acting steam pumps in which the pressure of the steam is communicated to the piston or plunger in the water end in a straight line through the medium of a piston rod, because of the absence of any revolving member to store up power during one part of the stroke and give it out at another, it is impossible to cut off the steam in the cylinder until the end of the stroke. Steady operation of these pumps is dependent upon the continuous and uniform pressure of the steam upon the steam piston throughout the entire stroke, the length of which is limited and controlled by the admission, release and compression in the steam cylinder.

Indicator cards taken from direct-acting pumps show practically uniform steam pressure at all parts of the stroke resulting in a card practically rectangular in form as shown in the illustration.

In the flywheel type of steam pump, energy is stored in the flywheel during part of the stroke so that the steam may be cut off at an early stage and allowed to work expansively as is done in all reciprocating steam engines employing flywheels, and the indicator card is similar to that from an engine in which the steam is cut off at a fraction of the stroke.



INDICATOR DIAGRAMS FROM DIRECT ACTING PUMP

To obtain a card from either a direct-acting or flywheel type of pump on steam or water end, use an indicator in the usual way and the area and power developed are determined as for any indicator diagram.

For the water cylinder a stiff spring must be used in the indicator to guard against injury at reversal of the stroke.

Details of Construction

In all but the smaller sizes of steam pumps, the steam pistons are of cast iron, hollow, and either made in a single piece or built up of 2 or more sections, depending upon the size of the pump and the type of the valve used. They are fitted with one or more metallic snap or built-up packing rings and are secured to the piston rod between a shoulder on the rod and a large nut with or without a lock nut at the end; straight, tapering, or combined straight and tapering fits are employed; in some of the smaller pumps the piston rod is screwed directly into the piston, no holding nuts being used.

Steam cylinders are generally of iron cast integral with the live and exhaust steam chambers and in some of the smaller sizes are even cast in a single piece with the yoke and water ends. As a rule, however, the cyl-

inder and steam passages are cast in one, the yoke supporting the crank-end head. The head-end cylinder heads are of the same material as the cylinder, and are bolted thereto by stud bolts, with a recess in the center of the head to give room for the nut at the end of the piston rod and obtain minimum clearance. In the duplex types, the steam cylinders are as a rule cast with the frame and in compound pumps are joined by a cast-iron yoke or spacer which forms one head for each cylinder.

Stuffing boxes are as for water ends, but of sufficient depth to allow 4 rings of packing and preferably have the bottom and the end of the gland chamfered in order to force the packing against the rod to prevent leakage.

While many methods are employed to entrap steam between the piston and cylinder head, to produce a cushion for the piston at the end of each stroke, one of the simplest of these consists of the use of 2 ports communicating with each end of the steam cylinder of which the outer is the steam port and the inner one the exhaust port. By this arrangement, when the piston approaches the end of its stroke, it covers the exhaust port and thus confines some steam in the cylinder, bringing the steam piston to rest gradually at the end of the stroke, and thus allowing the water valves to seat quietly.

As no use can be made of the expansive force of steam in direct-acting steam pumps, they do not use steam economically and in order to overcome this many of the larger units are provided with compound, and in some cases even triple expansion steam ends. Cylinders are usually placed tandem, the valves for both being driven from the same valve stem. Ordinarily the high-pressure cylinder is placed outside.

Single Cylinder Steam Ends

AS THERE is no flywheel to carry the pump past center and reverse the motion, this must be accomplished by some combination of reciprocating members and almost without exception some form of B or D valve is used. The D valve is of the usual type, except that it has no lap. It admits steam past the ends, and exhausts it through a center cavity, and must have motion the reverse of that of the piston which it controls, which can be obtained by using a reversing rocker arm.

The B valve has 2 cavities, one at each end, steam being admitted through one of these while it is being exhausted from the opposite end of the pump cylinder through the other one. It moves in the same direction as the piston which it controls, hence is well adapted for direct pumps.

To control admission and exhaust of steam for the auxiliary piston, usually used to move the main valve, an auxiliary valve is used. The possible combinations are, first, 2 D valves, the auxiliary valve being moved by a reversing rocker arm; second, a D auxiliary valve moved direct by the piston rod, and a B main valve; third, a B auxiliary valve, moved direct, and a D main valve. It would seem that a B valve might be moved direct from the main piston rod, but this has the difficulty that frequently the valve rod will stick and the pump become stalled.

A fourth method is the use of poppet auxiliary valves operated by the piston at the ends of the strokes to control the exhaust from the piston moving the main valve, pressure being maintained at each end of this piston by leak holes, usually through the ends of the hollow piston.

In all cases there are 4 parts concerned in the valve action, first the main piston rod and piston, second the auxiliary valve, third the valve piston, and four the main steam valve; and in duplex pumps this same condition pertains, since there are 2 main pistons and rods and 2 main steam valves, each piston rod controlling the valve on the opposite side of the pump.

There is no definite rule in regard to the size of the valve piston, but Nickel gives as common practice to make this 45 per cent of the diameter of the main piston.

As previously stated, it is desirable to have a slight dwell of the main piston at the ends of the stroke in order to permit seating of the water valves, and this is secured during the time required for the auxiliary valve to perform its function and permit the changing of the main valve by the action of the auxiliary piston.

Dwell of the steam valves during the stroke of the main piston is accomplished by a lost motion usually consisting of a sleeve and stops or a tappet acting on the ends of an oscillating lever. The action of these different parts will be understood by reference to commercial single cylinder pumps, which follow.

Single vs. Duplex

As between the single cylinder pump and the duplex type arguments may be summarized as follows: The single cylinder pump must stop during reversal, and this means the stopping of the flow of the column of water in both the suction and discharge pipes, which may in part be remedied by the use of air chambers but this tends to reduce the capacity of the pump; for high pressures the air will be rapidly absorbed; and the absence of air in the chamber will result in shocks and water hammer. The duplex pump, on the other hand, begins the stroke of one piston before the second piston has come completely to rest, so that the movement of the suction and discharge columns is more nearly continuous. The single cylinder pump, carefully set to give the maximum stroke, has less steam loss in the clearance spaces, and by the action of the auxiliary valve the length of the stroke is definite, regardless of rod friction, while in the duplex pump any friction on the piston, piston rod or valve rod may result in short stroking with reduced capacity of the pump and increased loss of steam in the clearance spaces. The single cylinder has few parts to keep in proper condition, few joints to leak and small radiating surface, while the duplex has simple valve gear, cannot stall, even when run at very low speeds, and is more expensive.

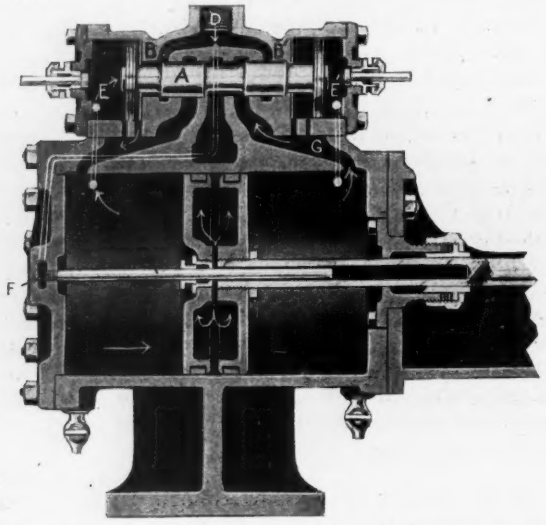
Because of these characteristics the single cylinder pump is particularly well adapted for wet vacuum and air pumps, since a considerable part of the work on the pump end is the handling of air and vapor and short stroking or large clearance materially reduced the

pump end capacity, while for the handling of high pressures, and especially where high or very slow velocity of flow is to be maintained the duplex type, on account of its more nearly continuous action, is often preferred.

Marsh Simplex Pump

In the Marsh pump, made by the American Steam Pump Co., the steam end has but 2 moving parts; steam valve and auxiliary piston are combined into one piece.

Referring to the sectional view, steam entering at D passes the reduced neck of the steam valve A, then down through the main left port to the head end of the cylinder, forcing the piston to the right. At the same time, it is passing through port E to the left of the valve head, thus keeping the left head of the valve in balanced condition.



SECTION OF STEAM CYLINDER OF SMALL SIZE MARSH PUMP

From above the valve, a port leads to F, thence through tube C steam is taken to the hollow piston rod and reservoir in the main piston, which is of spool form, each head having metal packing rings.

When the piston has moved to the right, the slot in the middle comes to register with the lower end of port E^1, permitting live steam to enter at the right of the valve head. At the same time, the main piston covers port G, so that the steam forces the valve to the left, closing the passage at B and opening a passage at B^1, also closing the upper end of port G and opening the left end of the main cylinder to exhaust.

The main piston covers port G slightly before the end of the stroke, trapping some steam to act as a cushion in bringing the piston to rest, but port E^1 does not register until the piston completes its stroke, thus preventing short stroking.

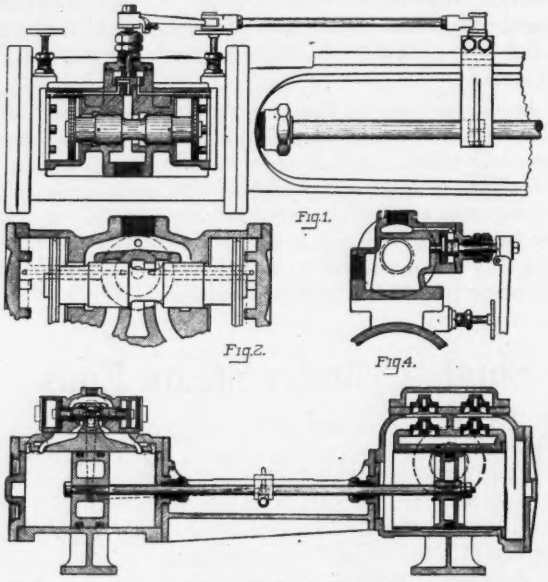
As the area of the valve head against which admission steam acts is less than that presented to cylinder steam, the position of the valve will be regulated by the pressure required in the cylinder to do the work. Heavy load, calling for high cylinder pressure, will act to force the valve to the right, enlarging the opening for admitting steam, and vice-versa.

When renewing gasket between steam chest and cylinder, pattern should be taken from the top of the cylinder—not from lower face of chest. Duplicate all holes and make sure that drilled ports at the ends are clear and register with the holes in the chest. For pumps of over 6 in. stroke, the passage at the top of the cylinder to carry trip steam must register in the head and cylinder, and a thin gasket be used under the head with a hole to connect the passages.

American-Marsh Single Pump

In this new pump made by the American Steam Pump Co., the steam valve, of balanced piston type, is combined with valve driving piston heads equipped with expansion rings, while the mechanically-driven auxiliary valve is of semi-rotative disk type on smaller sizes and Corliss type on larger sizes.

In the disk valve type shown herewith, steam at boiler pressure enters the top of the chest, filling the space around the main valve and through the drilled port shown in Fig. 4 to the space around the disk valve. In the position shown, steam is passing around the left neck of the main valve, past the left valve piston head and into the left port of the main steam cylinder; exhaust is passing from the right end of main cylinder around the center neck to the exhaust port.

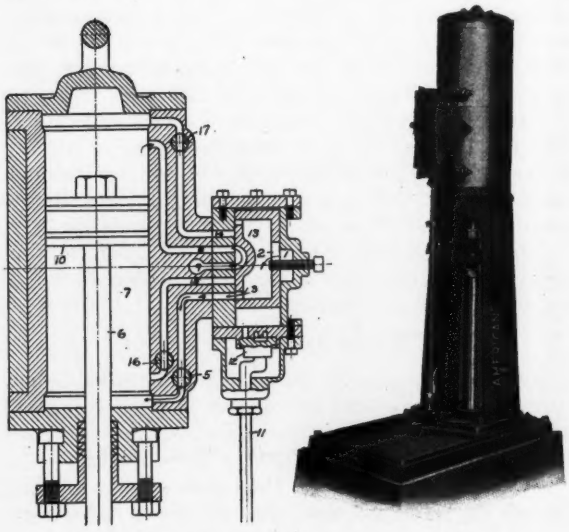


VALVE GEAR AND SECTIONAL VIEW OF AMERICAN-MARSH PUMP

In the auxiliary disk valve, the steam port, through the body of the valve, is shown in Fig. 1 admitting steam to the right of the valve piston, while exhaust from the left of that piston is passing through the chamber in the disk to exhaust, so that the main valve would be shifted to the left, reversing the flow of steam in the main cylinder. Length of stroke is regulated by the position of screws against which the rocker arm bears, and cushion is controlled by the valves in the small ports at the cylinder ends. Also the main valve will be so controlled by the action of cylinder steam pressure on its piston heads that the port area, hence steam taken, varies with the work required. The valve gear is claimed to prevent hanging up or racing under the most severe conditions.

American Deep Well Steam Head

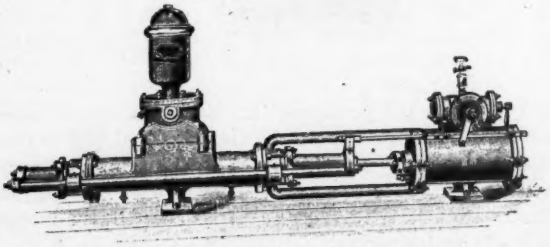
Designed to be placed directly over the well on a strong foundation, the single cylinder deep well steam head of the American Well Works has a balanced steam valve moved by a valve piston whose action is controlled by an oscillating auxiliary valve in the lower end of the steam chest.



AMERICAN WELL WORKS DEEP WELL STEAM HEAD

Steam enters the chest through pipe to chamber 1 and passes through ports 2, 3, 4 and choke valve 5 to the lower end of the cylinder 7. At the same time steam escapes from the upper end through ports 8 and 9.

Just before the piston 10 reaches the upper end of the stroke, it covers port 8, forming a steam cushion whose degree is regulated by choke valve 17 to give uniform up and down strokes. The valve stem 11 is turned by a finger cam moved by a roller on the crosshead, changing the position of auxiliary valve 12 so that steam will flow to move valve 13 to the bottom of the chest,



YOUGH SINGLE CYLINDER PUMP

uncovering port 14 to steam, and connecting port 15 to exhaust through port 9. Choke valve 5 controls the cushion on the lower end, and 16 the exhaust; the use of valves 5, 16 and 17 regulates the number of strokes, and the position of finger cams on the valve rod the length of the strokes. Where the weight of pump rods and pistons is greater than the water pressure, no steam is used on the down stroke, valve 17 being closed and valve 16 regulated to sustain the extra weight and give the required strokes.

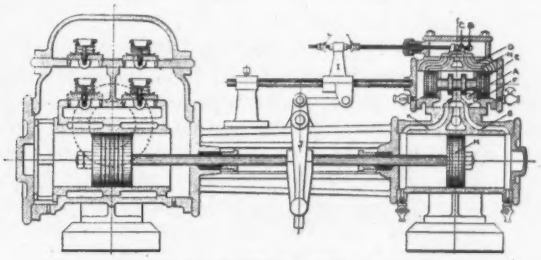
Yough Single Pump

Yough steam pumps, made by Boyts, Porter & Co., have a main D slide valve, with valve piston, controlled by an oscillating auxiliary valve at the side of the chest. The oscillating D valve is driven by tappets on a link from crosshead on the main piston rod, striking an arm on the stem of the oscillating valve. For emergency starting, the main valve may be moved by a handle extending through the end of the chest.

The steam piston has self acting packing rings, the water piston square piston packing, easily replaced. In large sizes, the piston rod is in 2 pieces connected at the center by a threaded steel pin, which allows either steam or water piston to be taken out without disconnecting the other end of the pump.

Buffalo Single Cylinder Steam Pump

A plain D auxiliary valve with cushion ports controls the auxiliary piston, which in turn drives a plain D main valve in this pump made by the Buffalo Steam Pump Co. Motion for the auxiliary valve C is derived

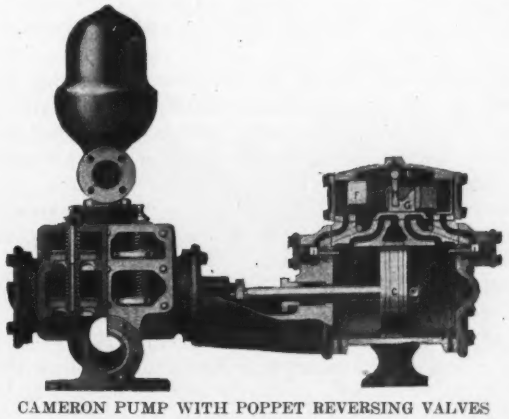


SECTION OF BUFFALO SINGLE PUMP

from the main piston rod by a rocker arm J pivoted on the top of the frame and connected by a drag link to a crosshead I, whose upper end moves between tappets on the auxiliary valve rod. Adjustment of the tappets to regulate length of stroke is easily made while the pump is running.

Cameron Single Pump

In the pump made by the A. S. Cameron Steam Pump Works, steam cylinder A carries piston C, which at the end of its stroke strikes reverse valve I and opens



CAMERON PUMP WITH POPPET REVERSING VALVES

port E to exhaust, through a passage running the length of the cylinder and shown dotted. Port E connects to the space at the end of the steam chest, which is kept filled with steam passing through small holes in the

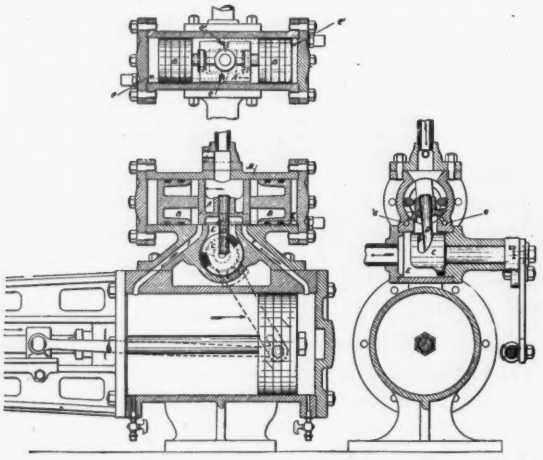
ends of the plunger. When this space is opened to exhaust, the steam pressure at the other end shifts the plunger F toward the end where the piston has opened the valve I, carrying main valve G with it and reversing the connection of steam and exhaust ports to the cylinder.

As soon as C releases it, valve I is closed by steam pressure entering through port K. As plunger F nears the end of its travel, it closes port E, entrapping steam on which it cushions.

Water valves are contained in a compartment at the side of the pump end, and are accessible on removing a bonnet, as shown at the right end of the pump cylinder. By unscrewing one plug in the top of the chest and pulling up the stem, both valves are released. The position of the chest brings it near the ground and close to the piston, giving short water passages and reduced suction lift.

Davidson Single Pump

Oscillation and sliding of the valve A by a cam acting on a pin inside the exhaust passage makes this valve serve also the purpose of an auxiliary valve, in the pump, made by M. T. Davidson Co. As shown in the sectional views, ports e e^1 lead from the ends of the steam chest through the walls to points near the center,



DAVIDSON SINGLE CYLINDER PUMP, SECTION OF STEAM END

the opening and closing of the inner ends being controlled by the oscillating and sliding of the valve A. Ends B B^1 of the valve piston are connected, but have sufficient space between for the valve A, which controls the main ports f f^1 by its longitudinal motion.

Action of valve A is as follows: Steam entering port f forces the main piston to the right, while exhaust passes out of port f^1. Cam C has moved pin D to oscillate valve A so that it is in proper position to open e to exhaust and e^1 to steam, and pin D is against the end of the slot in cam C, hence further motion of the main piston to the right will mechanically move valve A slightly to the left, positively closing ports f and f^1, giving slight cutoff and compression to bring the main piston to rest and prevent striking the head; also fully opening port e to exhaust and e^1 to steam, forcing the pistons B B^1 to the left, which will carry the valve A with them and open f to exhaust and f^1 to steam, reversing the motion of the main piston. The valve is actuated by a positive mechanical connection with the main piston rod and by the action of steam on the valve pistons, so that the steam piston cannot strike the heads, permitting the use of small clearance.

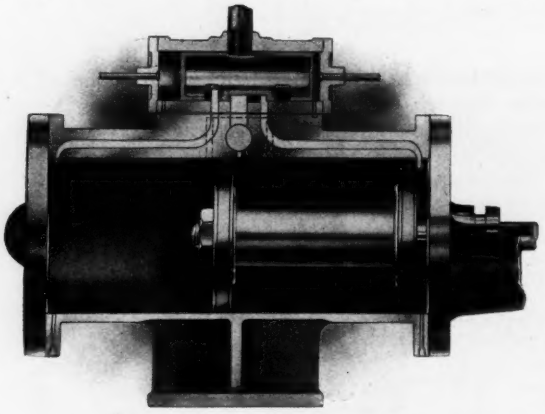
In the Davidson pumps for very high pressures, and for operation without internal lubrication, the cam C and pin D are not used; an oscillating auxiliary valve located in a chamber at the side of the exhaust passage controls ports exhausting steam from either end of the steam chest, permitting the valve pistons to throw, carrying the main valve; all parts of the steam chest are in balance as live steam is admitted to the ends of the chest at all times by holes through the valve pistons. As the valve piston throws, it covers the port through which pressure has been relieved and cushions on the steam in the end of the chest preventing striking.

The main valve in this type has only reciprocating motion and controls flow of live and exhaust steam to and from the main cylinder.

Dubois Simplex Pump

Automatic action by the use of a one piece hollow balanced valve, steam driven and controlled by the motion of the piston is the distinctive feature of the simplex pump made by the Dubois Iron Works.

Steam entering the valve chest passes to the cylinder through the main port and forces the piston to the right



SECTION OF DUBOIS SIMPLEX PUMP

until it passes the small port at the center, when steam passes through that port to the right of the valve, shifting it to the left and reversing the stroke. Operation of the valve is thus assured by action of full steam pressure, but the valve cannot move until the piston has made full stroke.

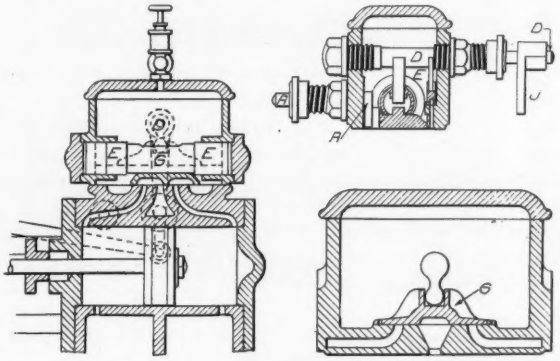
Outside rods are provided for moving the valve in case of sticking after long disuse. The central space between piston heads always carries steam at exhaust pressure, each head being fitted with a broad snap packing ring to ensure tightness.

Guild and Garrison Single Pump

The steam chest has a chamber at each end into which the ends of the auxiliary plunger fit. This plunger is central above the steam cylinder and has, at the bottom, a recess into which a projection extends from the top of the main valve, while the auxiliary rocking

D valve is located at the side of the plunger, and controls steam and exhaust ports leading to the chambers at the ends of the plunger.

From rock shaft D, two arms extend, one to move the auxiliary valve G, the other to move valve plunger E. Rocker arm J, which operates shaft D is driven by a link from the piston rod crosshead, a slot in the lower end of J furnishing a means of regulating the length of stroke of the piston.

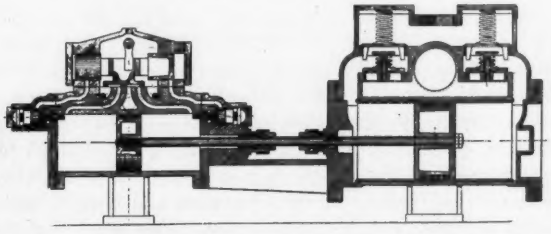


GUILD AND GARRISON SINGLE PUMP

The plunger is carried most of the way by the arm from shaft D, its travel being completed by action of steam controlled by the auxiliary valve, which gives gradual slowing down of the piston toward the end of the stroke, with prompt reversal.

National Single Pumps

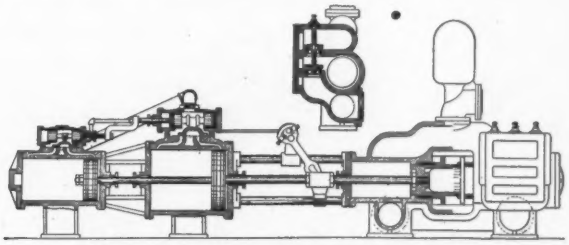
Tappet valves at each end of the cylinder are the means for reversing position of the auxiliary plunger and main valve in the Class A single cylinder pumps of the National Steam Pump Co. At the end of its stroke, piston comes in contact with one of the valves pushing it back and opening the corresponding port to exhaust. This relieves the pressure at one end of plunger and it moves toward that end, carrying the valve with it and reversing the flow of steam to and from the main cylinder, hence the motion of the piston.



CLASS A NATIONAL SINGLE PUMP

Except when relieved by the opening of a valve, pressure is maintained at both ends of plunger through the small holes in the heads. As the plunger passes over the end of the port, it cushions on the confined steam, coming to rest easily. As soon as released by the piston, tappet valve is closed by the steam pressure behind it acting through the dotted port.

Class B of the single pumps made by the National Steam Pump Co. have an auxiliary slide valve moved by a rocker arm and guide block from the main piston rod, and a valve plunger which moves the main valve of D type. At the beginning of its outward stroke the piston covers the main port, hence a pre-admission port is provided, which admits just enough steam to give the piston an easy start. This port is controlled by the outer edge of valve, and as soon as the piston uncovers the main port, full steam pressure enters. At the end of stroke, port is covered, and the piston is cushioned on the entrapped steam.



CLASS B NATIONAL SINGLE PUMP

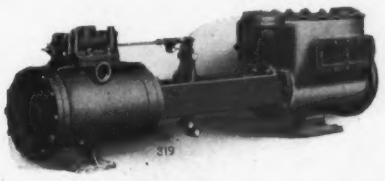
Meantime the lever has brought screw in contact with block and moved auxiliary valve to the right, opening one port to exhaust and admitting live steam to the other port, which causes the plunger to move to the right, carrying with it main valve, opening ports to live steam and exhaust.

Preadmission ports are provided for the valve plunger similar to those for the piston, giving cushioning and quiet action.

To adjust the stroke, set screws are moved in or out, while the pump is running until maximum stroke without hesitation at the end is secured.

McGowan Single Vacuum Pumps

Single direct-acting vacuum pumps are built by the John H. McGowan Co., with steam end equipped with the link motion type of valve gear which effects a positive and a uniform stroke during all stages of operation, a feature of importance in the operation of this type of equipment. The construction of the steam end is such as to permit of the condensing of the exhaust

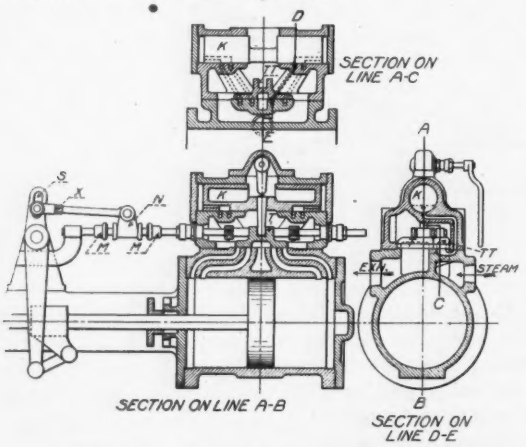


MC GOWAN SINGLE CYLINDER VACUUM PUMP

steam without affecting the operation of the pump. The vacuum cylinder is of the close clearance design with inverted intake valves and poppet discharge valves, thus adapting this particular design for operation in connection with evaporating systems. This type of pump is also used in connection with their steam tube type of surface condensers.

Smith-Vaile Single Cylinder Pump

This pump, made by the Platt Iron Works, has a tappet steam valve gear, operated by a rocker arm whose slotted lower end has a yoke end connected by link to the crosshead on the piston rod, and the upper slotted end S has a link connection X to a sleeve N moving on the valve rod, striking tappets M at the ends of the stroke and thus shifting the auxiliary valve TT on its seat in the side of the main valve chest. In this way, admission and exhaust ports leading through the auxiliary piston K to end chambers is controlled, which shifts the main valve T and thus controls admission and exhaust to the main steam cylinder.

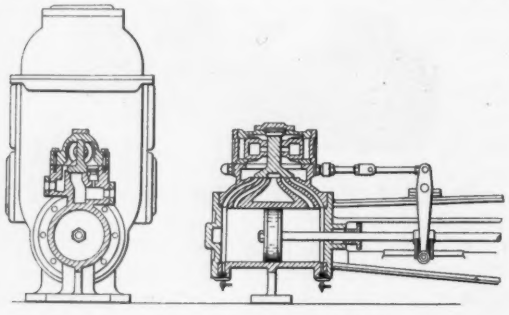


SMITH-VAILE SINGLE CYLINDER PUMP

Above the valve piston is a toe for shifting the auxiliary valve if desired, to permit starting the pump in either direction from any position. Length of stroke is controlled by the position of the link in the upper end of the rocker arm, and by the distance between tappet spools on the valve rod. Cushioning of both auxiliary and main pistons is accomplished by covering of the exhaust ports by the pistons, shortly before the end of the stroke is reached.

Scranton Single Cylinder Pump

Single cylinder air pumps, as made by the Scranton Pump Co., have a D main valve, driven by a valve piston, and an auxiliary slide valve, driven by a valve rod and connecting rod from a rocker arm whose lower end has a roller working in a sleeve crosshead on the piston rod. The auxiliary valve, of double-ported D form, travels on a seat at one side of the main valve, lost motion being provided in the connection of the rod to the valve. The main valve covers double ports which give a cushioning of the main piston at the ends of the stroke. The steam chest is a separate casting bolted to the top of the steam cylinder, so that by removing it, all parts of the valve gear are accessible.

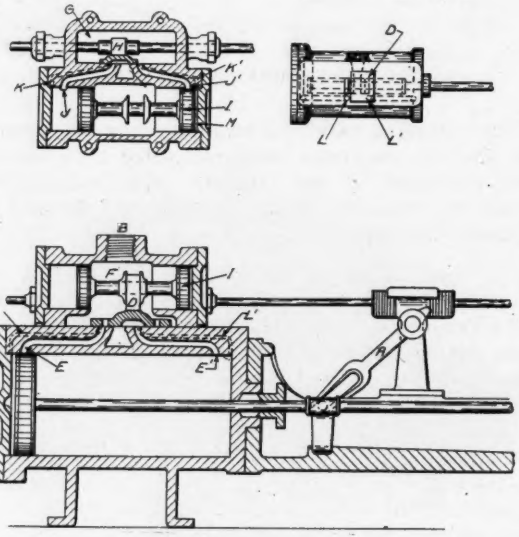


SCRANTON SINGLE STEAM END

Burnham Single Pumps

Burnham pumps, made by the Union Steam Pump Co., have single steam ports for admitting steam to cylinder, with only a small "preadmission port" for admitting steam to the extreme end of the cylinder. The small ports in the steam chest, which admit steam to shift the steam valve, are double, however, to give quiet action to the steam chest.

Auxiliary valve H, on a seat on the side of the main steam chest, is of D type, driven by tappets on the valve rod, adjustable to regulate the stroke. A roller attached to the main piston rod runs in the lower Y end of a rocker arm whose upper end moves the tappets so that the auxiliary valve moves in the reverse direction to the main piston.



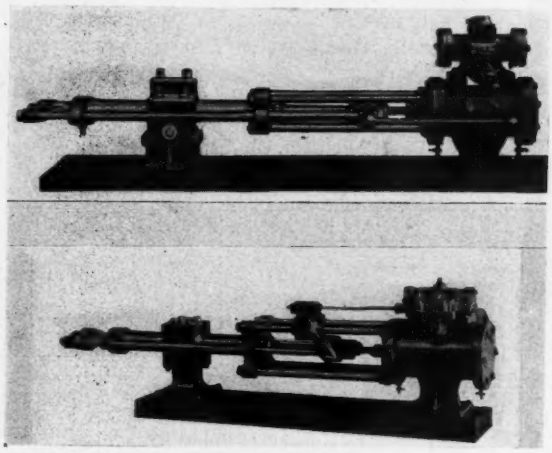
BURNHAM SINGLE PUMP

When valve H uncovers ports J^1 and K^1, the cylinder end of J^1 is covered by the valve piston, and steam flows to space M only through port K^1 until port J^1 is uncovered, when full steam pressure enters and piston I moves quickly to the other end of the chest, carrying valve D with it. Near the end, port J is covered by the left head of the auxiliary piston and the remaining steam is compressed into the clearance and port K cushioning the piston. The same action takes place for the main piston in ports E^1 L^1, E and L.

Watson-Stillman Single Cylinder Pumps

Two types of single cylinder pumps are made by the Watson-Stillman Co., Class D, for high pressures with water ends of steel forgings, with bronze valves, seats and bonnets for pressures from 250 to 10,000 lb. per sq. in. The steam end is like the Davidson pump, with reciprocating main valve and rotary pilot valve.

Class U is for pressures from 2500 to 10,000 lb. with pump chambers and passages bored from a solid steel forging, valves, seats, bonnets and glands of hydraulic bronze, and plungers which are outside packed of tool

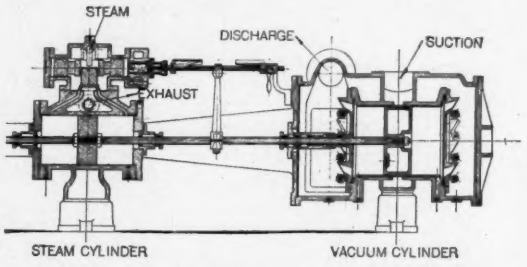


WATSON-STILLMAN SINGLE PUMPS, CLASS D ABOVE, CLASS U BELOW

steel hardened and ground. Steam end is like the Burnham pump, with reciprocating main and pilot valves of D form.

C. H. Wheeler Simplex Pump

In the C. H. Wheeler Mfg. Co., single pump, the Delamater valve gear is used, as shown in the sectional view. The upper end of the crosshead carries a pair of rollers which act on cams fastened to the stem of the auxiliary valve, rotating this valve which controls the exhaust of steam to the atmosphere from the spaces at the end of the auxiliary piston. This auxiliary piston



SECTION OF C. H. WHEELER SIMPLEX PUMP

engages, by a center opening, a projection on the top of the main D slide valve, and has live steam pressure admitted continuously on both ends. When the auxiliary valve is turned to allow exhaust to atmosphere from one end, the auxiliary piston moves toward that end carrying the main D valve with it.

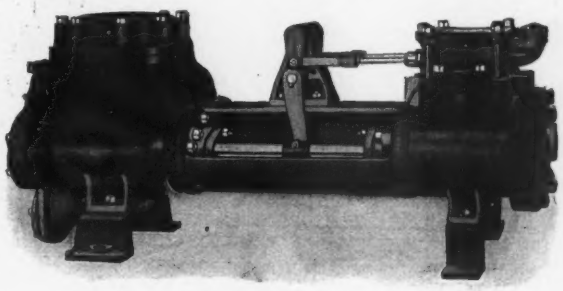
In the opinion of Robert Cramer expressed before the A. S. M. E., if steam pressures are increased to 600 lb. without using temperatures higher than those employed in modern practice the difficulties of design are not formidable and the results to be obtained seem fully worth the effort because thermal efficiencies closely approaching those of explosion engines can be realized with better overall economy.

Direct-Acting Duplex Pumps

DUPLEX pumps are characterized by the arrangement of cylinders and type of valve gear. The universal arrangement is to place 2 pumps side by side, the steam valve of one side being actuated through a system of arms, rods and links from the piston rod of the other side. In designating the side of the pump it is customary to call that to the right when standing at the steam end facing the water end of the pump the right-hand side, and that to the left, the left-hand side.

Differing somewhat from the ordinary type is that class known as twin or separable pumps which have, in general, the same arrangement of cylinders but the valve gear employed is of the simplex type with some sort of synchronizing connection between the valve gear of the 2 halves of the pump in order to secure equal service from both sides of the pump.

An excellent example of the latter type is the Burnham Twin pump, made by the Union Steam Pump Co., an illustration of which is shown herewith. It consists of 2 standard Burnham pumps placed side by side and run in step with each other, one keeping about ¼ revolution ahead of the companion pump. The result is ob-



ADVANCE DUPLEX PISTON PATTERN BOILER FEED PUMP

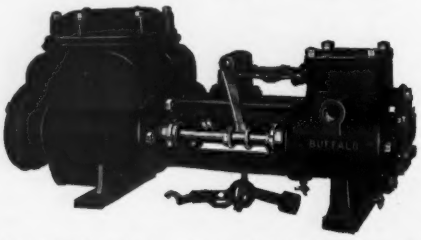
tained by a synchronizing valve located between the 2 steam cylinders and connected by the auxiliary pistons of the 2 pumps. This synchronizing device has no other influence on the operation of the pump than to keep them in step. Each pump controls its own valve motion, so that one side of the pump cannot cause the other to short stroke owing to variation of packing or other friction.

In this pump a complete set of stop valves is provided for steam, exhaust, suction and discharge pipes, so that by closing the proper valves either side of the pump may be stopped or removed while the companion pump is in operation.

The manner of connecting the 2 ends of the pumps differs with sizes of pumps, the purposes to which they are put and the ideas of designers. In some of the smaller sizes the entire main body of the pump and the feet or pedestal upon which it rests are cast in one piece.

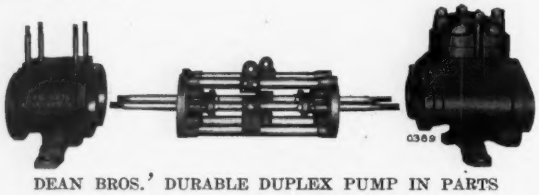
An example of the single casting type is the Union duplex boiler feeder, made by the Union Steam Pump Co.; in this case, however, a single heavy pedestal is cast under the center of the pump with the cylinders overhung.

In order to allow of more flexibility in the choice of water ends some manufacturers resort to the 2-casting construction. The steam cylinders and cradle being in one casting, which is bolted by studs to the water end, each end of the pump being supported on its own feet cast to the cylinders. This construction is employed in the Avance piston pattern boiler feed pumps.



BUFFALO PISTON PATTERN DUPLEX BOILER FEED PUMP

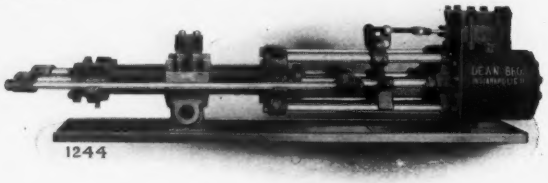
Further flexibility in the choice of steam and water ends, and a construction used almost universally in the larger pumps is permitted by the use of a separate casting for the connecting cradle, thus making the pump in 3 main castings. Examples of this construction are shown in the Epping-Carpenter and the Gardner pumps illustrated here.



DEAN BROS.' DURABLE DUPLEX PUMP IN PARTS

Pumps designed for high pressure, such as are encountered in marine boilers and hydraulic service, are quite frequently provided with rods to take the place of cradles.

All Dean Bros.' duplex Durable pumps, down to the smallest sizes, are made with separate steam and pump cylinders connected by rods. Should it be necessary to replace either the frames, the steam cylinders, or the pump cylinders, the cut illustrates how easily it may be done.



DEAN BROS.' STEAM DRIVEN DUPLEX FORGED STEEL HYDRAULIC PRESSURE PUMP

Dean Bros.' hydraulic pressure pump also is another example of this steel rod construction. In this case the water cylinders are forged steel and are made to work against any commercial hydraulic pressure.

A construction differing considerably from those described above is that employed in the Smith-Vaile vertical marine feed pump made by Platt Iron Works, which is designed for 300 lb. pressure. Here a central cast column supports the valve gear and takes its share of the strain between cylinders; in addition, however, 2 rods are provided for each side.

In addition to the increased strength given pumps by the rod construction they are, in general, more accessible than where cast cradles are employed.

As has already been illustrated, duplex pumps are made in both horizontal and vertical types, the valve gear employed being the same for both. In the case of vertical pumps, it is customary to arrange the cylinders with the steam end above the water end; this is advisable because the water end is the heavier; also to prevent steam binding when hot water is pumped, the water cylinders should be low so that water will come to them under pressure. The vertical pump is chosen when economy of floor space is of prime importance.

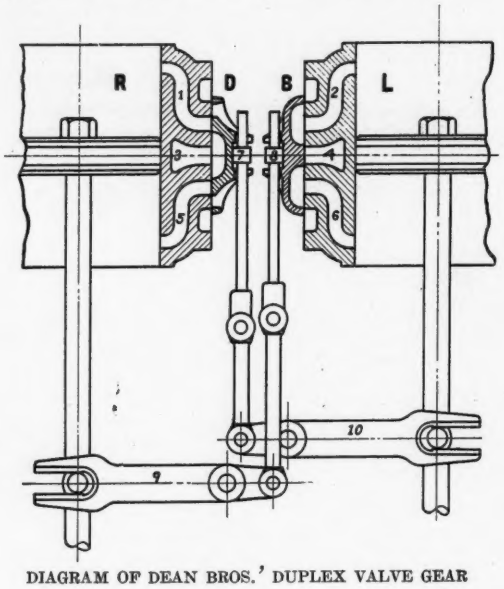


DIAGRAM OF DEAN BROS.' DUPLEX VALVE GEAR

General arrangement of cylinders in vertical pumps is well illustrated in the view shown of the Smith-Vaile pump.

Valve Motion

In the cross sectional view of the Worthington submerged piston pump will be seen a type of valve gear commonly employed on duplex pumps. The steam valve B is an ordinary D slide valve, and is worked through a rod and link by an indirect rocker arm; the valve for the other side of the pump is of the same type but is worked from a direct rocker arm; these arms, C, oscillate, swinging through the whole length of the stroke. Through this system of arms and links one piston rod acts to give motion to the steam valve of the other side of the pump, after which it finishes its own stroke and waits for its valve to be acted upon by the other side of the pump before it can start on its return stroke. This pause allows the water valves to seat quietly and obviates shocks. As one or the other of the steam valves is always open, there is no dead point, and the pump will start whenever steam is turned on.

Lost motion is a necessary feature of the valve gear of duplex pumps and in the Worthington pump this is provided in the connection of the valve to the valve rod; in other words, the lock nuts on the valve rod that move the valve are so placed that the rod will travel a short

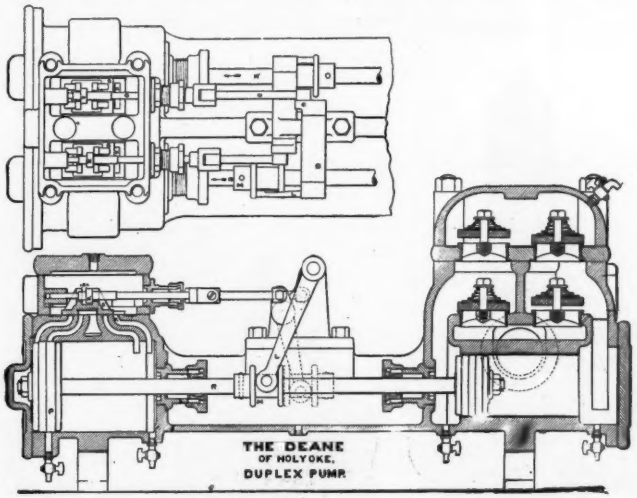
distance, at the beginning of each stroke, through the lug on the valve without moving the valve.

In the valve gear employed on the Dean Bros. duplex pumps the rocker arms are both of the indirect type, and the valve used on the right-hand cylinder is of a modified D type, while that on the left-hand is a B valve, both contained in one steam chest, cast separate from the cylinders. The ports in both cylinders are the same and are single with special cushioning features, as will be noted in the illustration of this gear. The cut is a sectional view of Dean Bros.' Durable duplex valve movement, which has been conventionalized to show the ports and slide valves. 1 and 5 are the D valve steam ports; 2 and 6 are B valve steam ports; 3 and 4 are exhaust ports, and 7 and 8 valve rod nuts. The steam cylinders are turned through one quadrant for convenience of showing the levers and steam valves. The levers on each pump are duplicates and interchangeable.

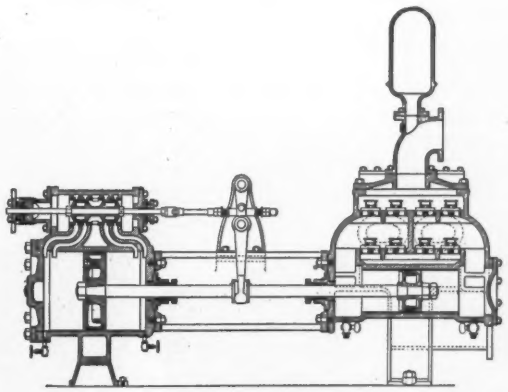
is necessary, this effect is accomplished in part at least by shifting the valve over the ports during the most rapid part of the pump stroke, for at the beginning of the stroke lost motion is being taken up in the valve gear, when the piston gets well started the valve is shifted across the ports during the rapid portion of the pump stroke.

In small pumps the crosshead attached to the piston rod consists of a block attached to the piston rod either by a pin or set screws. The end of the arm is made with a circular portion which works between the flanges of this block.

The block form of crosshead is employed on the Fairbanks-Morse boiler feed pump; one side of the block is drilled lengthwise to receive the piston rod, while a vertical slot is machined on the other side for the end of the rocker arm.



PLAN AND CROSS SECTION OF DEANE OF HOLYOKE DUPLEX PUMP



CROSS SECTION OF EPPING-CARPENTER DUPLEX PUMP

While the slide valve is the most common form used, piston valves are employed by some makers with the idea of giving a balanced condition to the valve and thus reducing friction and power necessary to operate the valve.

This type of valve is well illustrated in the sectional view of the Epping-Carpenter pump, where it will be noted not only the valve is balanced, but the valve rod extends through a stuffing box in the head end of the cylinder, thus eliminating the tendency of the valve to move when not being shifted by the rocker arm.

Details of Rocker Arms and Crossheads

Considerable liberty is left to the designer in regard to the details of rocker arms, and as a consequence there is much variation in this regard in the different makes of pumps. The office of the rocker arm, as stated above, is to transmit motion from the piston rod on one side of the pump to the steam valve of the other side. It is not essential that the motion of the valve be directly proportional to the motion of the piston; in fact, it is preferable to have the valve shifted rapidly when opening or closing ports, and, inasmuch as lost motion

The spool type of crosshead is illustrated in the cut of the Buffalo duplex pump, and has the advantage that the piston rod can turn without affecting the operation of the gear.

The form of the end of the arm used with this type is plainly shown in the view of the Deane of Holyoke pump, also the Scranton duplex piston pump, as well as several other of the pumps illustrated.

Another form of rocker arm end employed with a similar crosshead consists of a fork with prongs on either side of the rod. This type is clearly illustrated in the view of the Watson-Stillman pump shown herewith.

On the larger sizes of Gardner pumps a modification of this type and more elaborate form of crosshead and fork lever are employed, as shown in the detail view. A roller bearing reduces friction at this point to a minimum.

Some pumps are provided with a crosshead that forms also a coupling between the piston rods of the steam and pump ends. This form permits the use of different metals for the steam end and pump piston rods. The crosshead is split and clamped to the rods, and a guide is provided on the cradle which insures true run-

ning of the sliding block to which the rocker arm pin is attached.

Some crossheads are provided with a slot at right angles to the piston rod, in which a pin on the end of the rocker arm works, and still another arrangement is to have a pin on the crosshead over which the forked end of the rocker arm works, as seen in the section of Dean Bros.' pump valve gear.

Rocker arms slotted at the end to take the pin attached to the crosshead is another arrangement sometimes employed.

A link connection between the crosshead and the end of the rocker arm is an arrangement resorted to by the Platt Iron Works in the Smith-Vaile vertical marine pump, illustrated here, also by Guild & Garrison in their duplex injection water pump.

None of these devices need be complicated by means for taking up wear as a certain amount of lost motion is necessary in all duplex gears, and the only harm done by a loose fit at this point is the noise that may occur.

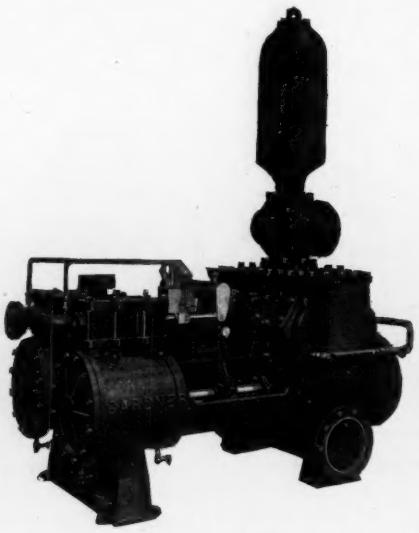
site side, and at that end of the lost motion block which is in contact with the link end.

The most common method of providing lost motion, particularly in moderate size pumps, is to allow clearance between the lock nuts on the valve rod and the lug on the valve. As a rule this clearance is properly adjusted in the factory for the conditions of operation, and to change the clearance the valve chest cover must be removed. This arrangement prevents indiscriminate readjustments by workmen without authority.

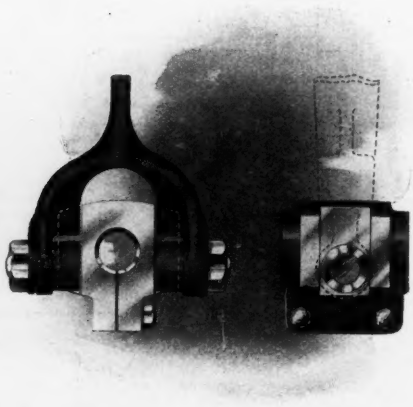
What is termed inside adjustable lost motion is provided on Worthington pumps, a cross section of which is shown herewith. In this case the lost motion can be varied or the position of the valve shifted as desired.

In the Deane of Holyoke pump fixed inside lost motion is provided, being governed by the thickness of the nut and the space between lugs on the valve, any change in clearance must then be made by providing a nut of different thickness; the valve, however, can be shifted by changing the location of the adjusting nut on the rod.

FAIRBANKS-MORSE PISTON PATTERN BOILER FEED PUMP, MEDIUM SIZE



GARDNER LOW-PRESSURE SERVICE PUMP



STYLE OF ROLLER BEARING USED ON GARDNER PUMP

While ordinarily the joint between the link and the valve rod has no support other than that given by the rod, in the valve gear of the Guild & Garrison pump the valve rod is provided with a crosshead which is supported by guides, thus relieving what strain might be put upon the stuffing box gland.

Provision for Lost Motion

Analyses of the operation of duplex pumps made it evident that for smooth, quiet working the piston should pause at the end of each stroke long enough for the water valves to seat before starting in the reverse direction. This effect is secured by providing lost motion in the valve gear. The amount of lost motion which will give best results depends upon conditions of operation and the design of the pump; if insufficient lost motion is provided, the pump will short stroke, if too much, the piston will strike the head. In general, the rule for adjusting the amount of lost motion is, with either side leading, to lengthen the stroke on the oppo-

In the disassembled view of the Scranton pump, a clear idea of the parts of a fixed inside lost motion gear is given.

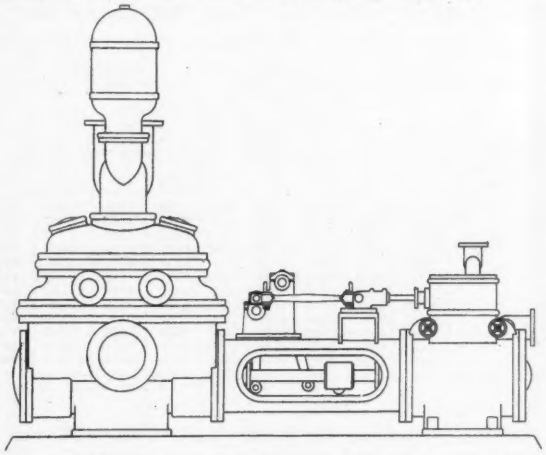
In the construction of large pumps, which are usually in charge of competent engineers, outside adjustable lost motion is provided. In these cases operating conditions are somewhat variable, and for highest economy the lost motion should be varied accordingly.

An example of this type of gear is shown in the drawing of the Epping-Carpenter pump, in which lost motion is provided by a sleeve around the link connecting the rocker arm to the valve rod.

Lost motion in the valve gear of some pumps is obtained by a sleeve on the valve rod, which operates between adjustable jam nuts.

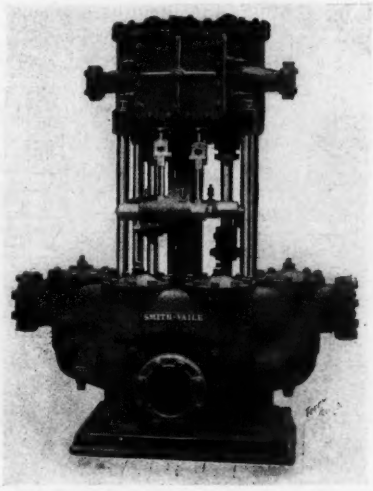
To get maximum capacity from a pump, it is necessary that the piston travel full stroke, for if the piston stops short of its full stroke, its capacity per stroke is reduced in direct proportion; the gain in the number of

strokes in any given time will not make up for the reduced length of stroke for time consumed at the end of each stroke in stopping and starting will be the same, so that while the number of strokes may be increased, the time lost at the end of the strokes is also increased in the same ratio, thus cutting down the actual time the piston is in motion and its pumping capacity.



GUILD & GARRISON PUMP SHOWING USE OF CROSSHEAD ON VALVE ROD

The cause of short stroke in duplex pumps is the admission of steam before the piston has finished its stroke; in other words, its steam valve has been acted upon too early, and this can be remedied by increasing the lost motion, thus delaying the motion of the valve.



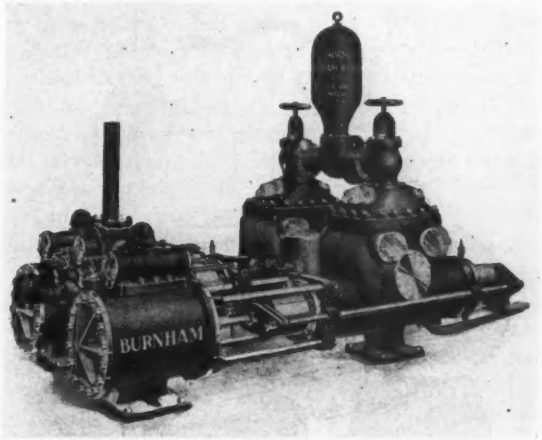
PLATT IRON WORKS SMITH-VAILE MARINE FEED PUMP, VERTICAL TYPE

Friction of piston rod packing will also cause short stroking, and is remedied by a more elastic packing, which will give a tight joint with less gland pressure.

Cushion

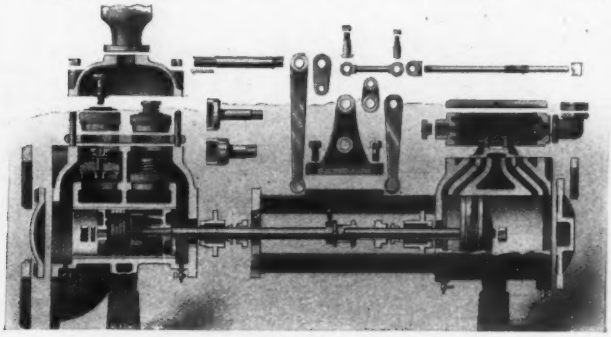
Pumps of the larger sizes having heavy reciprocating parts, which accumulate considerable momentum during a stroke, must be provided with some means for overcoming this momentum or the piston will strike the cylinder head.

One of the common means for providing this cushion is the double port arrangement. An illustration of this construction is given in the cut of the Deane of Holyoke pump; the operation is as follows: Steam is admitted through the outside port, k, driving the piston to the other end of the cylinder, exhaust passing from the cylinder to the exhaust port through the inner port at the other end until this port is covered by the piston; what exhaust steam then remains is compressed in the clearance space and the steam port, absorbing the momentum of the piston until it comes to rest without striking the head. When the steam valve is shifted, steam enters the head end of the cylinder and drives the piston on its return stroke.



BURNHAM TWIN PUMP MADE BY UNION STEAM PUMP CO.

In the cut of the Epping-Carpenter pump is shown this method of providing cushion when a piston valve is employed. When the conditions under which the pump will operate are known to be uniform, this method may be employed to good advantage, for it is simple and impossible to get out of adjustment.

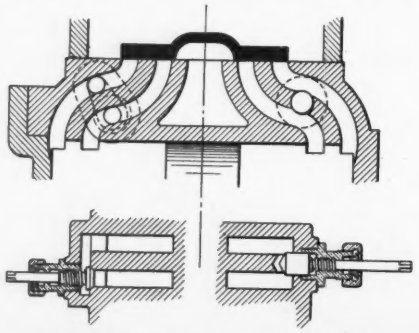


SECTIONAL VIEW AND PARTS OF SCRANTON DUPLEX PISTON PUMP

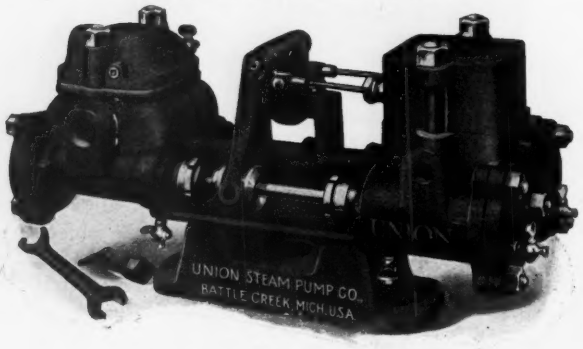
For pumps working under varying conditions, such as are met in water works plants, an adjustable cushion valve has some advantages. This valve is placed in an opening between the exhaust and steam ports, so that instead of compressing all the steam in the cylinder when the exhaust port is closed, the valve is so adjusted that it allows just enough steam to pass by to permit the piston to complete its full travel without striking the head.

These valves are so located that they may be adjusted at any time during the operation of the pump as will be seen in the views of the Guild & Garrison and Watson-Stillman pumps.

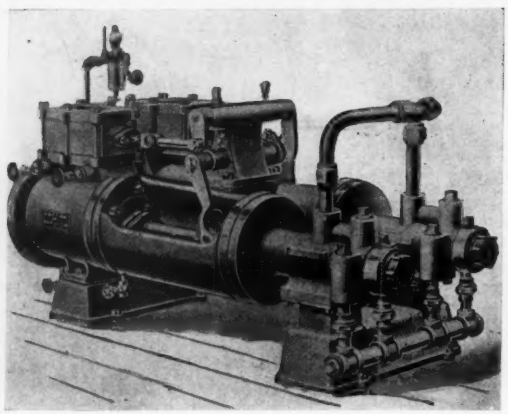
The proper length of cushioning, as may be inferred from the above, is governed entirely by operating conditions; it should be just sufficient to prevent the piston from striking the head, yet allow full stroke of the pump.



LOCATIONS OF CUSHION VALVES



UNION DUPLEX BOILER FEEDER



WATSON-STILLMAN DUPLEX STEAM HYDRAULIC PUMP

Rules for Valve Setting

Place the pistons in the center position, as follows: Mark the striking positions on the rod against the gland, then mark the rod half way between, when this mark is against the gland the piston is in the center of its stroke. When both sides have been placed, with pistons in mid-stroke, the valve motion arms should be perpendicular; if not, adjust the crossheads until they are. Then remove the steam chest covers and place the valves in mid-position. As there is no lap, the outer edges of the valve will be in line with the outer edges of the steam ports. Now adjust the rod clearance so that it is equally divided on either side of the valve rod nut; to start with, the total amount of clearance should be 0.3 the travel of the crank pin at contact stroke; this amount can be changed after operation if adjustments prove desirable.

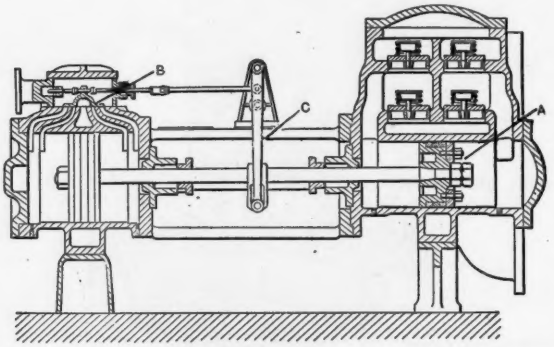
STEAM CONSUMPTION OF DUPLEX PUMP IN POUNDS PER HOUR AT 100 FT. PISTON SPEED

Diameter Steam Cylinders Inches	Initial Steam Pressure Pounds per Square Inch								
	50	60	70	80	90	100	110	120	130
10	1005	1160	1300	1440	1580	1720	1860	2000	2150
11	1220	1400	1570	1740	1920	2090	2260	2430	2600
12	1450	1660	1870	2070	2280	2480	2680	2900	3100
13	1710	1960	2200	2450	2690	2930	3160	3400	3650
14	1980	2270	2550	2830	3110	3390	3660	3940	4200
15	2260	2600	2800	3240	3550	3870	4190	4500	4850
16	2580	2950	3320	3680	4050	4400	4760	5120	5490
17	2910	3340	3750	4160	4570	4980	5400	5800	6200
18	3260	3750	4200	4650	5100	5580	6010	6500	6950
20	4030	4620	5190	5770	6330	6900	7450	8050	8600
22	4880	5590	6260	6950	7620	8300	9000	9700	10400
24	5800	6650	7450	8280	9100	9900	10700	11500	12400

Wilson-Snyder Mfg. Co.

Before replacing the valve chest cover, slide one of the valves over until it comes in contact with the valve rod nut; this will open one of the steam ports and put the pump in position to start when steam is turned on.

Directions for setting the Dean Bros., of Indianapolis, pump valves differ slightly from those given above for the reason that these pumps have one D and one B valve. The difference lies in placing the B valve in its center position; this is done by first placing the D valve in the center of its stroke; that is, in such a position that when looking through the opening in each end of the valve you will find all ports entirely closed. Now move the B valve until the ports on it are in line with those on the D valve, then adjust the valve rod nuts for clearance and proceed as directed above.



CROSS SECTION OF WORTHINGTON STANDARD SUBMERGED PISTON PATTERN PUMP

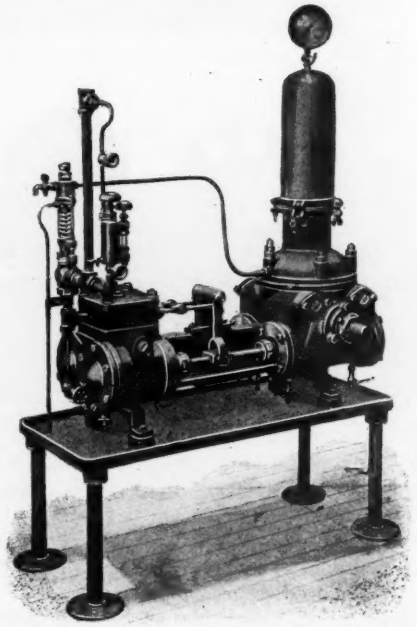
Pressure Regulating Pump

The duplex piston pressure regulating pump, made by The Witteman Co., and illustrated herewith, is designed to maintain constant pressure on the discharge line of the pump. The construction of the steam end is standard, but the liquid end is special, being made of cast iron, bronze or special composition, depending upon the material to be handled.

Pressure on the discharged liquid operates a steam controlling valve, thus maintaining a constant delivery pressure without attention from the operator. These pumps may be equipped with a special governor to secure constant rate of discharge, regardless of the pressure to be pumped against.

DIMENSIONS AND CAPACITIES OF COMMERCIAL DUPLEX PUMPS

Pump Sizes Inches				Maximum Cap. Per Min.		Pipe Diam. Inches			
Steam Cylinder	Water Cylinder	Stroke	Capacity G. P. Stroke	No. Single Strokes Ea. Piston	Gal. Both Cylinders	Steam	Exhaust	Suction	Discharge
2	1-1/4	3-3/4	.01	160	4.5	3/8	1/2	1	3/4
3	2	3	.04	160	13.0	3/8	1/2	1-1/4	1
3-1/2	2-1/4	4	.07	150	21.0	3/8	3/4	1-1/2	1-1/4
4-1/2	2-3/4	4	.10	150	30.0	1/2	3/4	2	2
5-1/4	3-1/2	5	.20	140	56.0	3/4	1-1/4	2-1/2	2-1/2
6	4	6	.35	130	84.0	1	1-1/2	3	3
7-1/2	5	6	.51	130	132.0	1-1/4	1-1/2	4	3
7-1/2	4-1/2	10	.69	108	150.0	1-1/4	1-1/2	4	3
9	5-1/4	10	.94	108	203.0	1-1/2	2	4	3
10	6	10	1.22	108	264.0	1-1/2	2	5	4
10	6	12	1.47	100	294.0	1-1/2	2	5	4
10	7	10	1.67	108	326.0	1-1/2	2	6	5
10	7	12	2.00	100	400.0	1-1/2	2	6	5
12	7	10	1.67	108	360.0	2-1/2	3	6	5
12	7	12	2.00	100	400.0	2-1/2	3	6	5
12	7	12	2.00	100	400.0	2-1/2	3	6	5
12	8-1/2	10	2.46	108	530.0	2-1/2	3	6	5
12	8-1/2	12	2.95	100	590.0	2-1/2	3	6	5
14	8-1/2	12	2.95	100	590.0	2-1/2	3	6	5
16	8-1/2	12	2.95	100	590.0	2-1/2	3	6	5
14	10-1/4	12	4.29	100	858.0	2-1/2	3	8	7
16	10-1/2	12	4.50	100	900.0	2-1/2	3	8	7



DUPLEX PISTON PRESSURE REGULATING PUMP

Where suction lift is considerable, the operation intermittent or the liquid contains a large amount of air, these duplex piston pumps are admirably adapted as they do not require priming.

THE WISE success-seeker profits by the experience of others who have camped along the trail before him. Consult men of successful experience, but do your own thinking. Most problems you meet have been solved successfully by others, improvements, however, are always in order.

Power-Driven Pumps

POWER-DRIVEN pumps, whether of the single or multiple cylinder type, are generally employed for boiler feeding, house supply, water works, sewage or filtration systems and in plants such as paper mills, tanneries, sugar houses, and the method of drive, which may be by means of belting from line shafts or by direct-connection to steam, gas or oil engines, electric motors or water wheels, depends to a great extent upon local conditions. For belt drive they are furnished with tight, or tight and loose pulleys, keyed directly to the crank shaft or to a pinion shaft, in which case single reduction gearing is employed; direct-connected units, due to the usual high speed of the drivers, are always fitted with single reduction and many times double reduction gears.

The pistons or plungers may be operated through the medium of connecting rods and piston rods, or single or double connecting rods only. In some pumps of this type, especially when used for deep-well service, a walking beam, one end of which is pinned to a connecting rod, attached to the plunger or the sucker rod, and the other end to a second connecting rod pinned to the crank, is employed. Eccentrics instead of cranks are used to a considerable extent, especially in the smaller sizes.

The cylinder arrangement employed depends upon the available head room and floor space. With ample head room, but limited floor space, vertical units are preferable, while if the head room is limited but sufficient floor space is available, the horizontal arrangement is the more suitable.

In order to prevent any tendency of the crank shaft to stop at the end of each stroke, resulting in non-uniform rotation, these pumps, especially when of the single-cylinder type, must be provided with some form of flywheel or be fitted with heavier pulleys and gears than ordinarily used. Due to the crank displacement and consequent more uniform turning moment in the 2, 3, 4, 5 and 6 cylinder units, the required flywheel effect is not as great as in the case of the single-cylinder pump.

APPROXIMATE HORSEPOWER REQUIREMENTS, SPEEDS AND PULLEY SIZES FOR SINGLE CYLINDER DOUBLE ACTING POWER PUMPS

Size of Pump Inches	H.P. per 100 Lb. Pres.	Speed R.P.M.	Pulley Dimensions Inches	Size of Pump Inches	H.P. per 100 Lb. Pres.	Speed R.P.M.	Pulley Dimensions Inches
1-1/4 x 2	0.20	65	12 x 1-1/2	10 x 10	22.00	45	24 x 6
2 x 2	0.24	65	12 x 1-1/2	12 x 10	29.72	45	24 x 6
1-3/4 x 2-1/2	0.28	65	12 x 2	3-1/2 x 10	2.35	42	18 x 3
2 x 3	0.42	60	12 x 2-1/2	4 x 12	3.96	42	18 x 3-1/2
3 x 3	0.62	60	14 x 2-1/2	5 x 12	5.30	42	18 x 4
2 x 4	0.80	60	14 x 2-1/2	6 x 12	7.94	42	20 x 5
2-1/2 x 4	0.86	60	14 x 2-1/2	7 x 12	10.86	42	20 x 5
3 x 4	1.00	55	14 x 3	8 x 12	15.94	40	20 x 6
3-1/2 x 4	1.65	55	14 x 3	9 x 12	18.80	40	20 x 6
4 x 4	2.15	55	16 x 3	10 x 12	25.00	40	24 x 6
3-1/2 x 5	2.87	55	18 x 3	12 x 12	32.86	40	30 x 6
4 x 5	3.11	55	18 x 3-1/2	14 x 12	46.14	40	
4-1/2 x 6	3.50	55	18 x 3-1/2	4-1/2 x 16	5.47	35	
5 x 6	4.49	55	18 x 3-1/2	5 x 16	6.69	35	
5-1/2 x 6	4.66	55	18 x 4	6 x 16	9.83	35	
4 x 8	5.22	55	18 x 4	7 x 16	13.06	35	
5 x 8	5.52	50	18 x 4	8 x 16	17.00	35	
6 x 8	5.40	50	20 x 5	9 x 16	21.46	35	
7 x 8	10.64	50	20 x 5	10 x 16	26.58	35	
8 x 8	11.32	50	20 x 5	11 x 16	32.25	35	
6 x 10	12.12	50	20 x 6	12 x 16	38.28	35	
7 x 10	13.00	50	20 x 6	13 x 16	44.82	35	
8 x 10	14.00	45	20 x 6	14 x 16	52.20	35	
9 x 10	21.00	45	20 x 6				

Arrangement of Valve Decks

Horizontal power pumps, like direct-acting steam pumps, may have their suction and discharge valve decks and chamber both above the cylinder or the suction valve deck and chamber below and the discharge valve deck and chamber above.

In vertical power-driven pumps various arrangements of valve decks and chambers are found; some manufacturers placing the suction valve decks and chambers on one side of the cylinders and the discharge valve decks and chambers on the opposite side, a trifle above the other; some prefer both suction and discharge valve decks and chambers on one side only, while still others,

APPROXIMATE HORSEPOWER REQUIREMENTS, SPEEDS AND PULLEY SIZES FOR TRIPLEX SINGLE ACTING POWER PUMPS

Size of Pump Inches	H.P. per 100 Lb. Pres.	Speed R.P.M.	Pulley Dimensions	Size of Pump Inches	H.P. per 100 Lb. Pres.	Speed R.P.M.	Pulley Dimension
1-1/4 x 2	0.30	65	12 x 1-1/2	10 x 10	31.00	45	42 x 8
2 x 2	0.32	65	12 x 2	12 x 10	44.60	45	
1-3/4 x 2-1/2	0.40	65	12 x 2	3-1/2 x 12	3.45	42	
2 x 3	0.70	60	12 x 2-1/2	4 x 12	5.95	42	
3 x 3	0.90	60	14 x 3	5 x 12	8.25	42	
2 x 4	1.22	60	15 x 3	6 x 12	11.90	42	
2-1/2 x 4	1.28	60	15 x 3	7 x 12	16.28	42	
3 x 4	1.52	55	16 x 3	9 x 12	23.93	40	
3-1/2 x 4	2.40	55	16 x 3-1/2	9 x 12	23.22	40	
4 x 4	3.15	55	18 x 3-1/2	10 x 12	34.60	40	
3-1/2 x 6	4.30	55	20 x 3	12 x 12	49.30	40	
4 x 6	4.65	55	20 x 4-1/2	14 x 12	69.22	40	
4-1/2 x 6	5.10	55	20 x 4-1/2	4-1/2 x 16	8.00	35	
5 x 6	6.75	55	22 x 5	5 x 16	10.00	35	
5-1/2 x 6	7.10	55	24 x 5	6 x 16	14.35	35	
4 x 8	7.80	55	26 x 5	7 x 16	19.60	35	
5 x 8	8.30	50	28 x 5	8 x 16	25.60	35	
6 x 8	11.10	50	30 x 6	9 x 16	32.20	35	
7 x 8	16.00	50	30 x 8	10 x 16	39.88	35	
8 x 8	17.00	50	36 x 4	11 x 16	48.30	35	
6 x 10	18.20	50	36 x 4	12 x 16	57.40	35	
7 x 10	19.50	50	36 x 6	13 x 16	67.20	35	
8 x 10	21.00	45	36 x 6	14 x 16	78.30	35	
9 x 10	30.00	45	42 x 8				

especially in the larger size of pumps, employ 2 sets of suction and discharge valve chambers, one located on each side of the cylinders. Whatever style employed, they are placed as near the cylinder as possible, and all water passages are made with large radius curves to aid the flow of the water as much as possible and prevent the formation of air pockets.

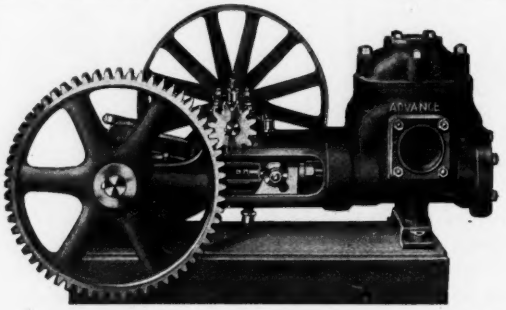
To eliminate the use of large, heavy and cumbersome valve chambers large power pumps, as a rule, employ individual valve chambers or pot valves contained in separately cast compartments.

Multiplex Power Pumps

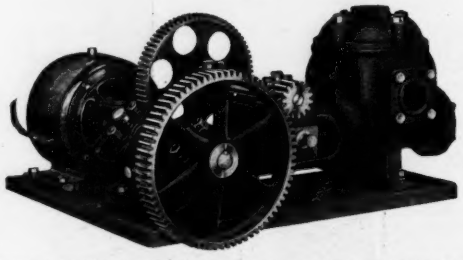
Power consumption curves of single-cylinder, single and double-acting pumps, and 2-cylinder single and double-acting pumps with cranks displaced at 180 deg., show a minimum consumption at the ends of the strokes with a maximum between; or in other words, the power requirements and consequently the torque will rise and fall twice during each revolution of the crank shaft. With a 2-cylinder pump having cranks displaced 90 deg., one cylinder will be working at full capacity while the plunger of the other is passing the dead center, and as a result, the power curve will tend to become smoother. Three cranks, displaced 120 deg., have a still greater effect in smoothing out the power curve and evening up the crank-shaft torque.

The permissible plunger speed of single or multiple cylinder units depends to a great extent upon the nature of the fluid handled, the working pressure, the size and form of suction, discharge and valve chamber passages, and the type of valve and valve seat employed. A conservative estimate from figures given by manufacturers places the maximum permissible plunger speeds for pumps handling clear liquids and fitted with rubber or metal disk valves at about 100 ft. a minute, for pumps handling heavy fluids and fitted with ball valves, at approximately 60 ft. a minute, while in those used for extra high-pressure service, considerably lower plunger speeds are employed.

As the efficiency of a machine such as a power-driven pump employing reduction gears, depends to a great extent upon the efficiency of the gearing, it is essential that in design and operation this be maintained at as high a value as possible. Due to its adaptability, durability and higher efficiency, spur gearing, except in special designs, is invariably employed. Within fixed limits,



ADVANCE DUPLEX POWER PUMP, BELT DRIVEN, PISTON TYPE



ADVANCE DIRECT MOTOR DRIVEN DUPLEX POWER PUMP, PISTON PATTERN

its efficiency increases as its speed, and from a series of experiments reported by Kent, we find that with pitch line velocities of 3, 10, 40, 100 and 200 ft. a minute, the efficiencies ranged as high as 90, 93, 97, 98 and 98.5 per cent respectively. Increasing the number of reductions and gear ratio decreases the efficiency. For belt-driven units, pulleys keyed direct to the crank shaft or single reduction gears are used, while where high speed driving units, such as electric motors, are employed, double or even triple reduction gears may be found; other medium speed direct-connected units, such as gasoline, oil or steam engines, require but single reduction gears.

Advance Duplex Power Pumps

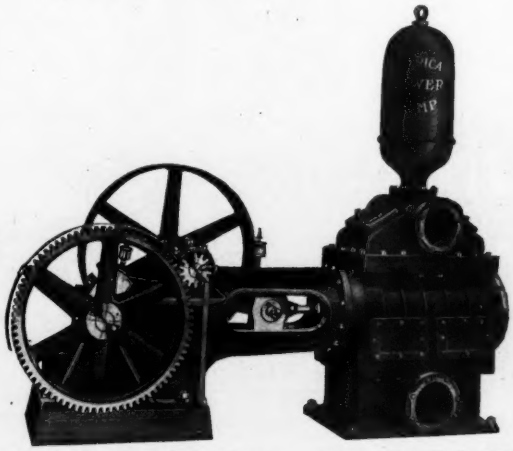
These pumps, which are ordinarily made with capacities ranging from 36 to 380 gal. per min., are provided with water ends similar to those used on the regular steam-driven type of duplex pump as made by the same builders, in which the water cylinders are lined with brass, the seats, stems and springs are of bronze, and the valves of hard rubber, soft rubber or brass.

The frames of these pumps are made in one casting, with the crank shaft bearings at one end and those for the drive shaft located above the guides. The pinion and gear are of machine-cut charcoal iron, while the connecting rod and crank shaft are of mild steel with adjustable bearings at all points.

Advance Duplex Power Pumps are built by the Advance Pump & Compressor Co.

American Power Pumps

The power frame is of cast iron of the heavy girder type, with bored guides and carries babbit-lined crank and counter shaft bearings, the latter being placed on top of the frame near the end of the guides and the former at the end of the frame approximately in line with the piston rod. Riding in the upper bearings is the steel counter shaft to which is keyed the overhanging pulley and steel, bronze or rawhide pinion meshing with the cast-iron machine cut gear, fitted to a steel crank shaft. The crosshead connected to the crank by a steel connecting rod provided with a babbit-lined crank box and bronze-lined crosshead box with wedge and bolt adjustment is made of cast iron with adjustable bronze shoes turned to fit the guides. The pin joining the connecting rod and crosshead is of steel, while the piston rod and gland are of bronze.



AMERICAN GEARED POWER PUMP, EXTRA HEAVY PATTERN

Bolted to the frame is the cast-iron, bronze-lined cylinder supported by a cast base and carrying the valve and air chambers.

American Power Pumps are manufactured by the American Steam Pump Co.

Barnes Horizontal Double-Acting Power Pump

This pump consists of a water cylinder mounted on a cast base plate and carrying the pinion and crank shaft bearings, piston rod guide and air chamber.

The pinion shaft is fitted with overhanging tight and loose pulleys and pinion, the latter meshing with an internal gear keyed to the crank shaft. Outside connecting rods pinned to the crosshead impart motion to the piston rod and piston. The suction and discharge valves, which are of the rubber-faced type working on brass seats are all placed above the cylinder.

This pump is built by The Barnes Manufacturing Co.

Yough Triplex Power Pumps

Two heavy uprights bolted to a cast brass plate, upon which is also mounted a cast pier carrying the driving motor, are used as supports for the pinion shaft, crank shaft and crosshead guides. The crank shaft is made of cast steel, is of the solid 3-throw type, and operates the 3 crossheads and plungers through the medium of steel connecting rods provided with adjustable brasses.

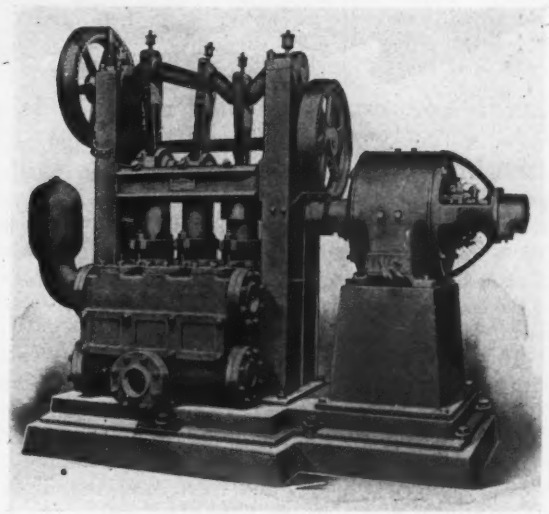
BARNES HORIZONTAL DOUBLE-ACTING POWER PUMP

The water valve chamber consists of a single casting mounted on one side of the pump, and is provided with 3 suction and 2 discharge openings, air chamber and handhole plates which give ready access to the valves.

These pumps are built by Boyts, Porter & Co.

Buffalo Power Pumps

These pumps, built by the Buffalo Steam Pump Co., are made in the single-cylinder, double-acting horizontal, duplex single-acting vertical, and double-acting horizontal, and the triplex single-acting vertical types.



YOUGH TRIPLEX POWER PUMP

The single-cylinder, double-acting units are built up of the cylinder, air chambers and the head carrying the crank shaft bearing. The pinion bearing bracket is cast integral with the cylinder and carries a shaft fitted with

overhanging loose and tight pulley and pinion, the latter meshing with a gear on the crank shaft with a reduction of 5 to 1. Motion is imparted to the plungers by connecting rods joining a sliding T head and the 2 cranks, one of which is of the solid disk type, while the other is a gear-wheel spoke used for that purpose. Two horizontal rods bolted to lugs cast on the sides of the cylinders form riding supports for the T head, to the center of which is bolted the piston rod connected to a leather packed piston.

In the vertical single-acting duplex pump, the frame is built up of 2 A-shaped uprights bolted to an iron base plate and joined midway by heavy spacing rods bolted to lugs cast on the sides. Large babbit-lined bearings at the top of the standards carry the crank shaft fitted with a tight-and-loose pulley at its center and overhanging disk cranks at the ends. Pinned to these cranks are the connecting rods operating adjustable crossheads built integral with the plungers, which operate in guides supported by and placed outside of the standards. Directly below the guides and bolted to the base plate are the 2 cylinders provided with adjustable stuffing boxes.

Horizontal pumps of this type and make are equipped for either belt or direct drive.

Pedestals on top of the frame carry the pinion shaft to which is keyed an overhanging pinion meshing with a gear keyed to the crank shaft, which in the smaller sizes is supported by 2 bearings and in pumps having strokes greater than 6 in., by 3 bearings. The crank shafts are open hearth steel forgings with the cranks displaced 90 deg. Bronze connecting rods are employed in the smaller units, while those used in the larger sizes are of cast steel.

Buffalo single-acting triplex power pumps are made with slight modifications in 4 forms known as Classes K, L, M and N.

The frame of Class K pump is cast in one piece with the crosshead guides and cylinders. Openings for connection between cylinders and valve chest are carefully finished, insuring a tight joint, and steel bolts are inserted by means of which the valve chest is attached. The 2 crank shaft bearings on top of the standards, as also in pinion shaft bearings which are located on the back of the frame, are lined with babbit metal.

On regular standard pumps, crank shafts of open hearth steel castings are used, while for special work forged steel crank shaft may be obtained; the cranks, one of which is of the overhanging solid disk type, are displaced at 120 deg. Pumps of 2-in. stroke have the plungers operated by means of eccentrics on the shaft, but all other sizes have regular pattern connecting rods made of open hearth steel and fitted with babbited bearings at the crank end and bronze bushings at the crosshead end. Cylindrical crossheads cast in one piece and running in bored guides are used in sizes 4 by 4 in. and smaller; sizes 3½ by 6 in. and larger are fitted with adjustable babbited shoes and are of such construction that the crosshead pin operates under oil at all times. On pumps 3½ by 6 in. and larger, when brass plungers are used, the crosshead and plunger are separate and bolted together.

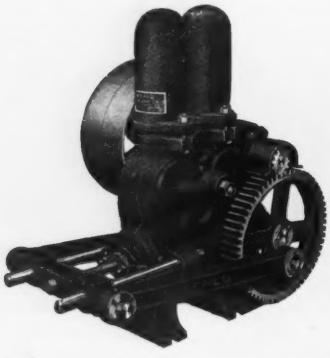
The plungers have slightly rounded or conical ends so as to eliminate shock and water hammer and are made of hard cast iron, except in the 1¼ by 2-in. size, which has bronze plungers.

Bolted to the cylinders is the valve chest consisting of a one-piece casting machined to template, and provided with a cover plate allowing ready access to the valves and chambers. In the smaller pumps, the valves are reached through plugged openings.

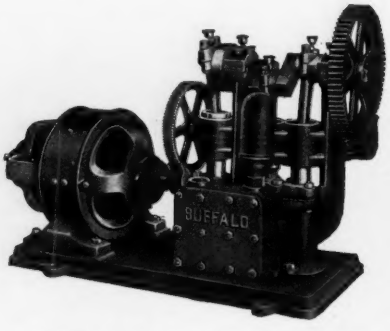
In Class L triplex pumps, the frame consists of 4 standards, which in sizes 6½ by 8 in. and less, are cast integral with the cylindrical crosshead guides. In the larger sizes, the standards, guides and bases are bolted together. Crank shaft and pinion shaft bearings are babbited, peened and scraped to fit. The gear and pinion used are of charcoal iron cut from the solid.

The connecting rods joining the cranks and crossheads are open-hearth steel castings provided with adjustable babbited boxes at the crank end, while solid bronze bushings are used at the crosshead end in all sizes up to 5½ by 8 in. for 50 lb. maximum working pressure. Larger sizes have wedge adjustment at the crosshead end.

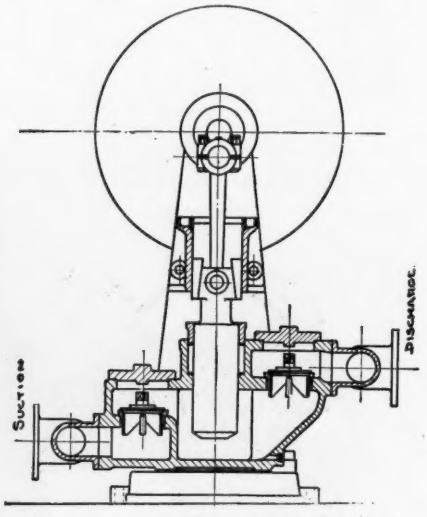
Cylinders and plungers are of single-piece castings provided with cast-iron glands, allowing ample packing



BUFFALO SINGLE-CYLINDER, DOUBLE-ACTING POWER PUMP



BUFFALO CLASS K TRIPLEX PUMP, DIRECT CONNECTED

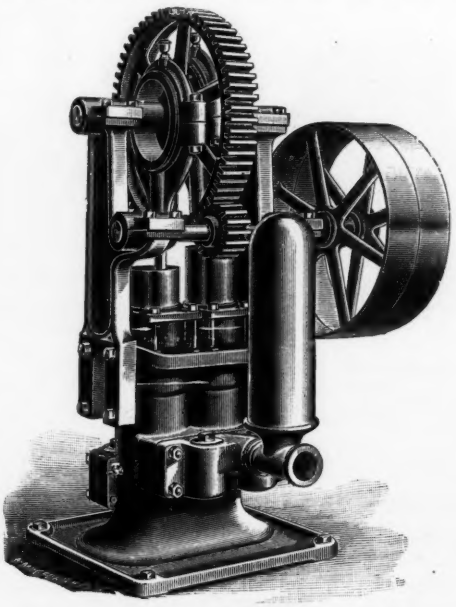


SECTIONAL VIEW BUFFALO DUPLEX POWER PUMP

space, although for special service bronze lined cylinders, plungers and glands are furnished.

As in Type K pumps, the valve chest is of one casting with large valve area and direct water ways and is equipped with the same kind of valves, seats and springs.

Classes M and N triplex pumps embody units having capacities up to and including 1500 gal. per min., and except for the heavier form of construction employed, the general lines of the machines belonging to these 2 classes are similar to those of Classes K and L.



THE DAVIS DUPLEX POWER PUMP

Heavier connecting rods fitted with adjustable babbited boxes on the crank end and bronze boxes with wedge adjustment at the crosshead end, separate crosshead guide casting, multiple type valve boxes, separate cylinders and double gears and pinions are some of the features of the pumps belonging to Classes M and N.

Davis Power Pumps

These pumps, designed for boiler feeding, hot water pumping, pulp mill and general service, are built as duplex, double duplex, triplex, double triplex and quadruplex units and for low and high-pressure work.

The uprights or frames are of the box pattern, cast integral with the cylinders. Pinion or drive shaft bearings are supported by brackets cast on the side of the frame, while those carrying the crank shaft are placed as shown. Power is transmitted by means of a loose-and-tight pulley keyed to the pinion shaft through single reduction gearing, the gear of which is mounted on the crank shaft between the eccentrics operating the plunger rods. In the triplex pump 2 gears are used, each mounted between 2 eccentrics.

All pumps are fitted with outside packed plungers.

To the bottom of the cylinders are bolted the chambers, containing the valves readily reached by removing caps, each held in place by 3 bolts. The valves in the pumps used for general service are of composition, while in pumps used in pulp mills and in places where sandy or muddy water, chemicals or heavy solution, soap, etc., are handled, the valves are hollow composition balls

Double duplex and triplex pumps are made up of 2 single units mounted on a common bed plate and fitted with a single drive shaft having a loose and tight pulley mounted between the 2 units.

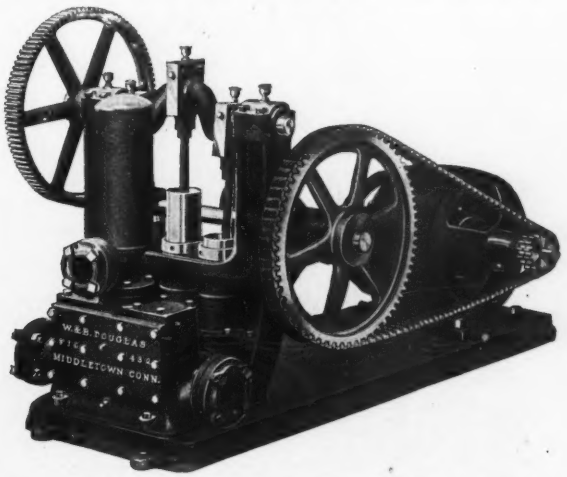
Davis Power Pumps are manufactured by I. B. Davis & Son.

Douglas Triplex Power Pumps

As ordinarily supplied, these pumps are of the single-acting, outside-packed type and of the general form of construction shown in the accompanying figure, which illustrates a motor-driven unit.

A forked frame, cast integral with the cylinders, is bolted to a cast-iron base containing the valve chambers, access to which is had through removable cover plates, and so arranged that the suction pipe may be connected at either end of the chamber.

A solid cast-steel crank shaft riding in adjustable bearings and with cranks spaced 120 deg. apart, operates plungers, receiving its motion from the driving pulley through a pinion shaft carried in bearings supported by brackets cast at the side of the frame, and meshing with an overhung gear keyed to the crank shaft. These pumps are manufactured by W. & B. Douglas.



DOUGLAS SINGLE-ACTING PUMP WITH MOTOR AND SILENT CHAIN DRIVE

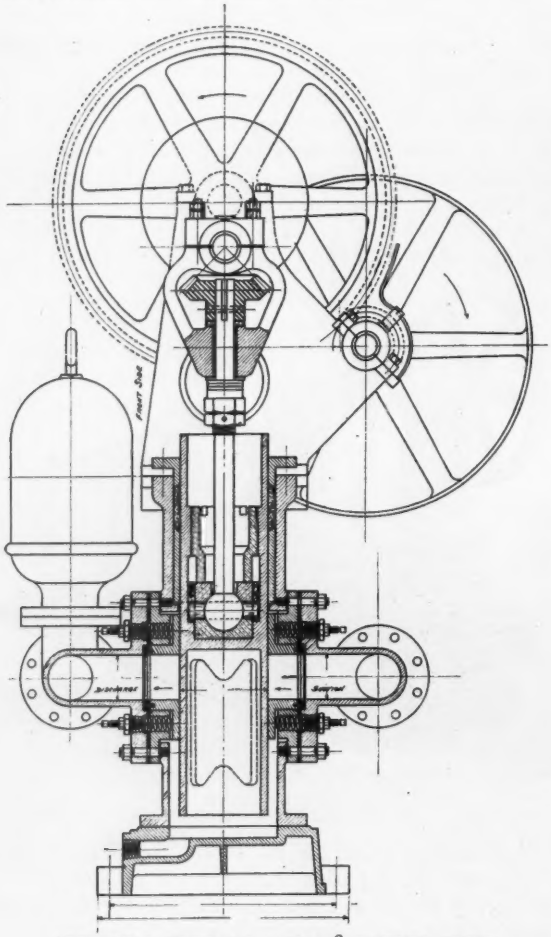
The Dourte Pump

Distinctive features of the Dourte pump, made by The Dourte-Hassell Manufacturing Co., are the rotary movement of the piston and the absence of all valves.

General construction of this pump consists of a heavy bed plate upon which are bolted the 2 cylinders in the smaller sizes cast integral with the crank and pinion shaft bearing brackets; in the larger units independent supports bolted to the bed plate are used. The crank shaft is driven from the pinion or pulley shaft by pinion and spur gear of a ratio of 5 to 1. On the end of each crank pin is fixed a miter gear, meshing with one of the same size keyed to the upper end of the connecting rod. The lower end of the connecting rod is attached to the piston by a flexible or universal

joint while the crank or gear end is held in a yoke which keeps the gears at all times in proper mesh, and at this point is provided with a ball thrust bearing.

The piston is a hollow casting open at both ends and divided by a nearly centrally located web forming upper and lower compartments. The former holds the universal joint consisting of a ball and socket and pin with a ring nut to take up wear; in the lower section, also hollow and open at the bottom, is the port which alternately engages the suction and discharge openings and performs the function of valves.



SECTIONAL VIEW OF A NO. 6 DOURTE PUMP

The cylinder castings have stuffing boxes and glands of the style used on standard pumps. Below, the cylinder is bored to fit the piston for a sufficient length to act as a guide and at this point is provided with a renewable bushing.

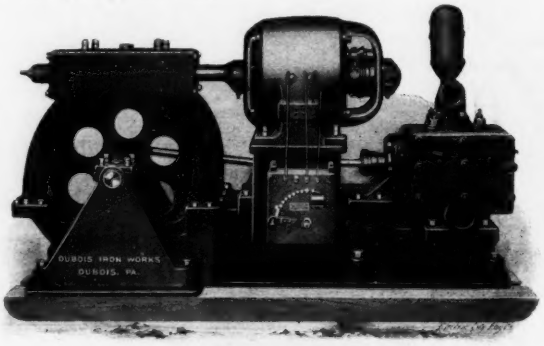
Du Bois Power Pumps

These pumps, built by Du Bois Iron Works, are made in the horizontal, single-cylinder, double-acting type, arranged for belt or direct drive by electric motor or gas engine.

When electric motor drive is employed, the motor is mounted as shown and the power transmitted by means of a worm meshing with a gear keyed to the crank shaft; when gas engines are used, double reduction spur gears are employed. Cylinder and crosshead guides are bolted to the cast-iron frame with which is cast in one piece the 2 crank shaft bearing pedestals.

Forged steel connecting rods and crank shafts are employed, the former with crosshead end bored for a bronze bushing, and the crank end fitted with a babbit-lined bronze box. All bearings are babbit-lined. The crosshead is of cast iron and either operates between 2 slotted guides bolted to the frame or upon a single steel guide rod.

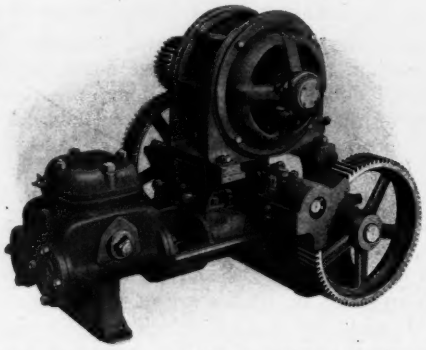
Four or more rubber valves, depending upon the size of the pump, are used.



DU BOIS CLASS T MOTOR DRIVEN PUMP

Gardner Duplex Power Pumps

These pumps, built by the Gardner Governor Co., are made in packed piston, center packed plunger, and plunger and ring styles. They are built upon guide frame and bearing pedestals cast integral and bolted to the water ends which in turn rest upon cast-iron supports. When belt-driven, single reduction gears are employed, and when driven by an electric motor, double reduction is used, the pinion shaft being carried in bearings attached to the top of the frame.



GARDNER CLASS P. M. A. PACKED PISTON POWER PUMP

All but the larger sizes of the packed piston type pumps are regularly furnished with brass-lined water cylinders, brass-lined stuffing-box glands, bronze gland studs and Tobin bronze rods; the larger sizes of packed piston and center-packed plunger pumps are fitted with cast-iron, removable cylinder liners.

Valve seats, springs and bolts are of brass, the seats screwed into the decks on a taper, thus removing the possibility of their coming out under pressure. The valves are of rubber or brass and when of the latter are of the regrinding cap type.

Goulds Triplex Power Pumps

These pumps, built by The Goulds Manufacturing Co., are made in single-acting plunger and double-acting piston types.

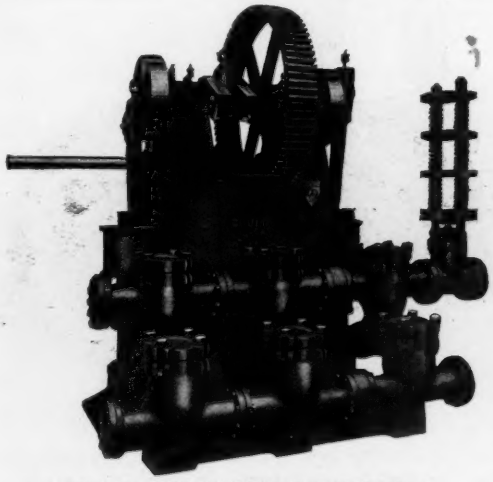
The frames of the smaller sizes of single-acting type consist of 2 standards held together by a center crosshead guide and a center cylinder seat, each of the standards providing seats for each of the other cylinders on the outside of the casting.

When belt driven, power is transmitted through a tight-and-loose pulley keyed to a shaft, supported by 2 extended babbit-lined bearings, and fitted with 2 pinions meshing with the 2 main gears. These are in turn, keyed to the crank shaft, turning in phosphor-bronze lined bearings.

For high-pressure service, the valve boxes are of the pot type cast separately, but bolted together and provided with tongue and groove joints; for medium and heavy service, they are made in one piece.

Goulds Triplex Double-Acting Plunger Pump of horizontal construction, is built in the outside end or outside center-packed style, in both of which 3 heavy cast-iron girder sections, each carrying a main bearing and crosshead guide and bolted and doweled together form the frame. The main crank shaft bearings are of standard 3-part box design with wedge and screw adjustments; pinion shaft bearings are of 2-part design with adjustable boxes. All bearings are babbit lined.

In the outside end-packed pump, the front cylinders fit into counterbores in the main frame and are securely bolted thereto. The valve boxes are located directly above and bolted to the cylinders, and are of the pot type.



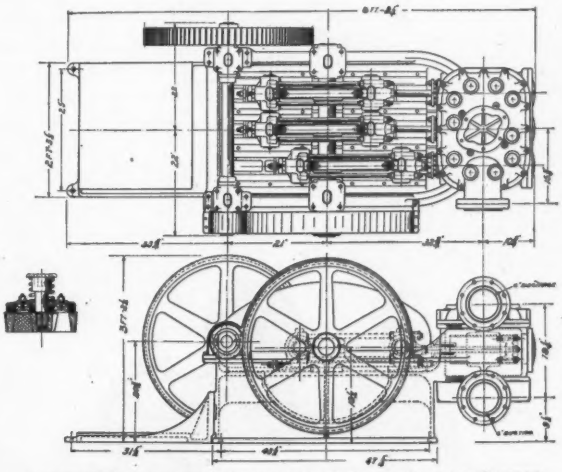
GOULDS SINGLE-ACTING TRIPLEX PUMP

In both types of pumps, the plungers are of hard cast-iron ground true and smooth; in the outside-end packed machine the plungers are bolted directly to the crossheads, while in the outside-center packed types they are operated by rods working through a bronze-lined stuffing box.

Hill Double-Acting Power and Electric Pumps

This pump is built up of cylinder and combined bearing and crosshead guide casting bolted to a heavy bed plate.

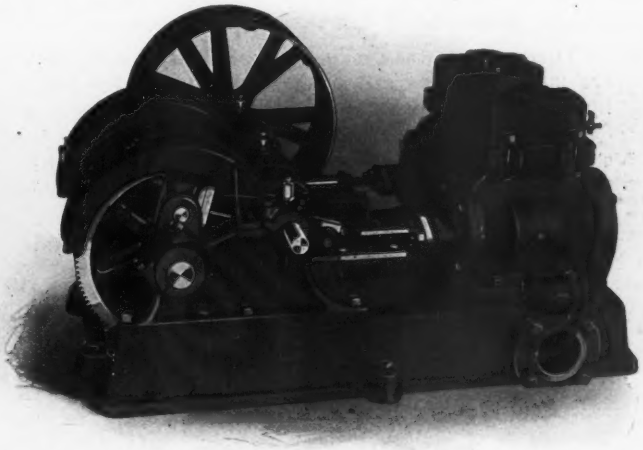
The upper bearings at the end of the crosshead guides carry the pinion shaft to which is keyed 2 double pinions, each meshing with double gears. These gears, supported in the bearings and gudgeons, are joined by hydraulically pressed-in wrist pins.



LUITWIELER TYPE B DOUBLE-ACTING, NON-PULSATING TRIPLEX PUMP

Forged steel connecting rods fitted with brass boxes join the wrist pin and crosshead, the latter being held in place by guides cast in the frame. Stuffing boxes with long glands are provided.

This pump is built by the Hill Pump Co.



HILL DUPLEX DOUBLE-ACTING POWER PUMP FOR HIGH DUTY

Luitwieler Non-Pulsating Triplex Pumps

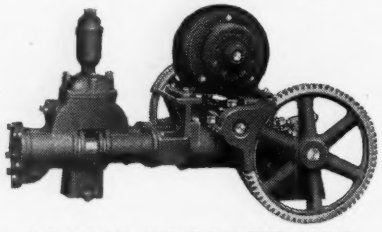
In the Luitwieler Non-Pulsating Triplex Pumps, made by the Luitwieler Pumping Engine Co., in single and double-acting types, the rotative motion of the drivers is changed to reciprocating motion by means of cams acting directly on the crossheads instead of cranks.

The frame is a casting rectangular in shape to one end of which are bolted the cylinders and valve chambers. the 4 bearing boxes for the drive and cam shafts are on either side of the rectangular frame.

The pistons are made in 3 parts, having leather cap rings which expand under pressure, preventing water slip.

McGowan Single and Duplex Power Pumps

These pumps, which are built by the John H. McGowan Co., are furnished by the builders with direct shaft driven from belt or motor for the use of separately mounted driving units or for top or side direct-connected motor mountings. The frames combine the crosshead guides, packing-box yokes, main bearings and the pinion shaft bearings for gear reductions when used, and are Both single and duplex types are adapted to the same change of pump ends as the steam-driven types with piston rod packing box screwed directly into the inner head of the pump cylinder, so as to permit the direct bolting of the pump body to the frames. These packing boxes are provided with a shoulder to secure and maintain the alinement of the pump body with the steam



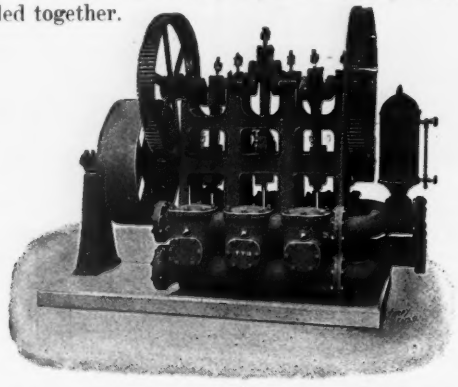
MC GOWAN DUPLEX POWER PUMP

end or power frame. Another special feature is the equipping of the packing boxes with brass screwed swivel gland packing box nuts, which form permits the withdrawal of the glands without disturbing the piston rod packing.

Smith-Vaile Triplex Power Pumps

These pumps, the product of The Platt Iron Works, are made in single and double-acting types, for both light and heavy pressures.

The main power or bearing frame is of the 2, 3 or 4-standard type, varying according to the service to be performed. On the smaller sizes, the frames and water boxes are cast in one piece, while the larger sizes are sectionalized and the various parts securely bolted and doweled together.



SMITH-VAILE TRIPLEX, DOUBLE-ACTING PUMP

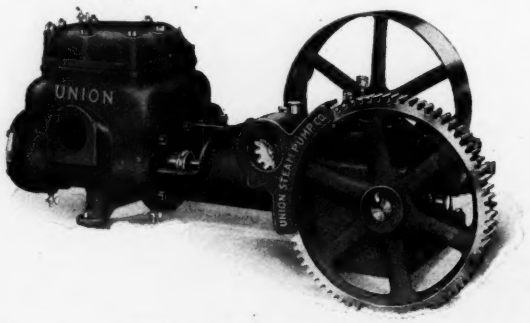
Malleable iron or steel connecting rods are employed in all sizes of these pumps. The smaller ones are equipped with marine-type crank-pin boxes and the larger ones with boxes of the strap end type.

Smith-Vaile power pumps are also made in horizontal triplex, single and double acting and in horizontal duplex double acting units.

Union Power Pumps

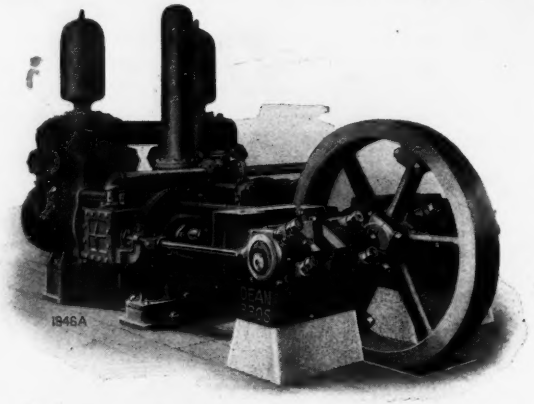
These pumps are built by the Union Steam Pump Co. in the single cylinder and duplex types.

In the electrically driven pump the motor is mounted directly on the frame and connected to the crank shaft by double-reduction gears cut from solid blanks. To one end of the crank shaft, supported by adjustable bearings, is keyed a gear meshing with a pinion on the pinion shaft, while to the other end is keyed a solid-disk crank.



UNION DUPLEX POWER PUMP

In the duplex type the 2 cylinders are cast in one piece and bolted to the frame. Power is applied to the crank shaft from a pulley through single-reduction gear, or if direct connected or electric drive is employed a double reduction is used. The crank shaft, to which is



DEAN BROS. CRANK AND FLYWHEEL DUPLEX PUMP

keyed the driving gear of the overhanging type, is supported by babbit-lined bearings and is so constructed that the pins are set at angles of 90 deg. with one another.

Dean Bros. Crank and Flywheel Duplex Pump

This machine is built with the fork frame, engine type construction, each frame being provided with 2 bearings, one on each side of crank, maintaining absolute alinement. The double frame permits a very strong, double throw crank shaft, made from one solid forging. The cranks are offset at 90 deg., to provide uniform discharge. The flywheel is placed between the 2 center bearings.

Any type of pump end may be used to fit the service required, except for heavy hydraulic work, when it is preferable to keep to the simple duplex design.

Crossheads are of the adjustable type, with micrometer screw adjustment.

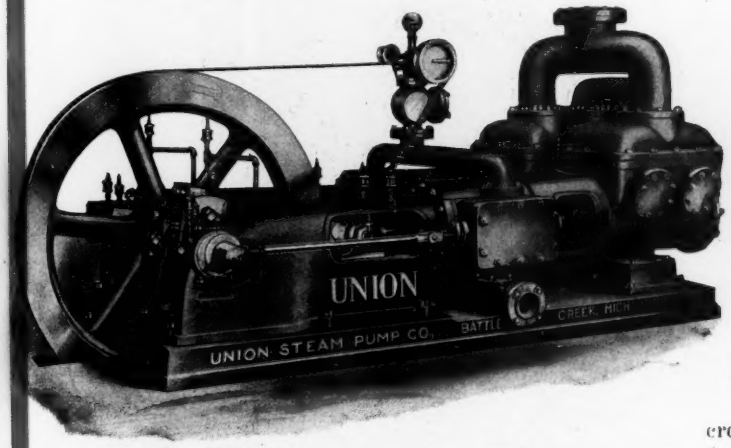
Cylinders can be made either simple or compound, with or without Meyer gear slide valves.

Single pumps are also manufactured on the same general lines. This pump is built by Dean Bros. Steam Pump Works.

Union Duplex Flywheel Pumps

Union duplex steam driven flywheel pumps are built for general service by the Union Steam Pump Co.

The steam and water cylinders are set tandem together with the crank case and guide frame and are bolted to a heavy cast-iron sub-base extending under the entire unit. A 2-piece flywheel fastened at rim and hub is keyed to the center of the crank shaft, which is of forged steel with pins on the quarter.



UNION DUPLEX STEAM DRIVEN GENERAL SERVICE CRANK AND FLYWHEEL PUMP WITH MEYER CUT-OFF

Eccentries mounted on the overhanging ends of the crank shaft operate the steam valves, which may be either of the plain D slide valve or of the adjustable Meyer cutoff design.

Deane Power Pumps

These pumps are built in the horizontal and vertical, single, duplex, triplex and quintuplex inside packed piston and outside packed plunger types. In the horizontal, single acting units, power is delivered to an overhanging pulley on the pinion shaft, carried in bearing brackets located on top of the frame, and to the opposite end of which is keyed an overhanging machine cut pinion meshing with a gear fitted to the end of the crank shaft.

Where liquids are to be handled, which carry much grit or foreign matter in suspension, the plunger type is more suitable. The general design of the power end of this type is similar to that of the piston type, the greatest difference of design and construction being in the water ends, which are of the form shown.

The horizontal duplex type is built double acting, inside packed, outside center packed or outside end pack-

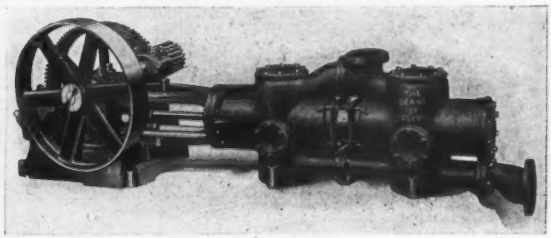
In the inside packed piston pattern, the frames and yokes are heavy rolling-mill-engine type, the latter carrying bored guides.

In the outside packed double-plunger type each set of valves is in a separate chamber.

In Deane triplex power pumps, pillar or column design of frame is employed, the larger sizes having uprights, the number of which depends upon the capacity of the pump and the type of duty for which it is designed, cast separate and bolted to the base.

The crank shafts, which are of composite design, with crankpins set at angles of 120 deg., are supported by babbited bearings at the top of the uprights; the center crankpin is a part of the main shaft, while the outer ones are mounted on disks forced onto the ends of the shafts by hydraulic pressure.

Quintuplex power pumps are of the single-acting type, built with 2 and 4 uprights, the latter provided with and without yokes above the cranks connecting the top ends of the uprights, and arranged for direct connection by either placing the motor on an extended base plate or mounting it on top of the main frames. Solid



DEANE HORIZONTAL SINGLE, DOUBLE-ACTING PLUNGER TYPE POWER PUMP, OUTSIDE CENTER PACKED PATTERN

crosshead guide castings, bolted between the uprights, further serve to increase the rigidity of the machine.

In all but the larger sizes, overhung gear wheels are employed, which in all cases, however, are keyed to solid crank shafts supported by 2 and 4 bearings, depending upon the type of support used.

These pumps are built by The Deane Steam Pump Co.

Deming Power Pumps

All Deming power pumps built by The Deming Co. embody the principle of the 3-throw crank shaft, with the crankpins at angles of 120 deg. with each other so

The main bearings, or guide columns of the geared pumps, are of the box girder type and contain 2 bearings, which support the crank shaft between the cranks. Integral with the crank shaft, which is made of open hearth steel cast in one piece, is a large flange to which is bolted the main gear.

In all pumps, the plungers are of the outside guided type and are provided with crossheads which, except in the smaller sizes, have bronze shoes admitting of adjustment for taking up wear and run in guides bored to a true circle.

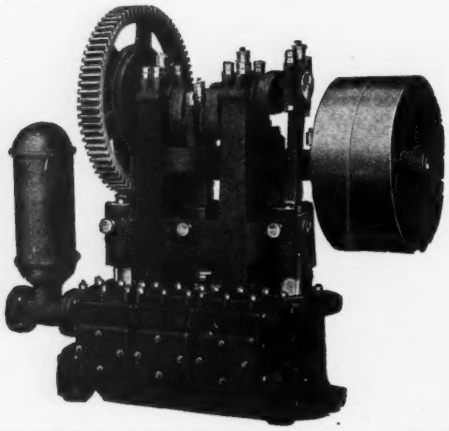
Except in the smaller sizes, the valve chambers are separate but bolted to the cylinders, have large valve areas, and are provided with large handholes having removable covers.

Scranton Triplex Power Pumps

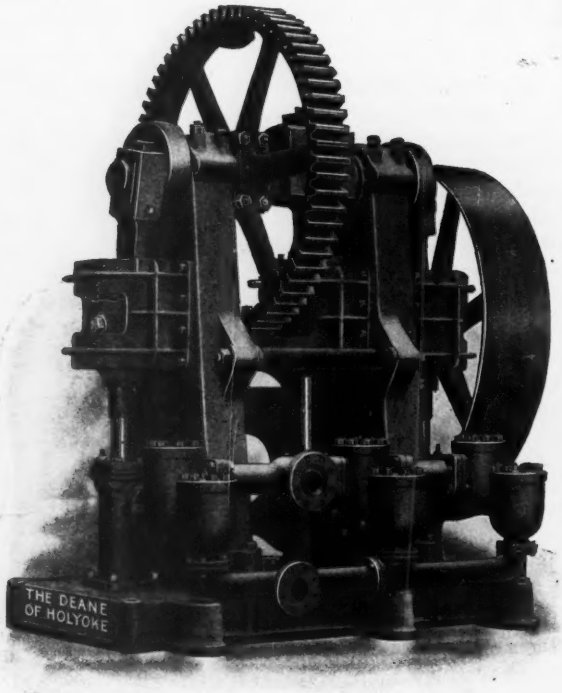
Each part of these pumps is sectionalized so that all are interchangeable; a divided water end allows the valve chamber to be removed from the cylinders.

Housings of the box or girder frame type, cast separately and tied together by cradle and water cylinders with turned bolts in reamed holes are used.

The cradle guides, which include the crosshead, are made of heavy castings which rest on ledges cast in the housings and are secured by turned bolts in reamed holes. The crossheads are separate castings of iron or steel with adjustable bronze shoes and are turned to fit in bored guides.



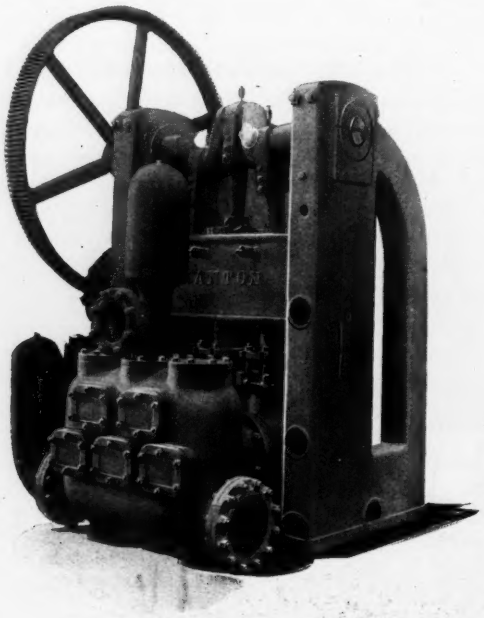
DEMING SINGLE ACTING TRIPLEX PUMP FOR GENERAL SERVICE



VERTICAL TRIPLEX SINGLE-ACTING POWER PUMP, HEAVY PRESSURE POT VALVE TYPE

The valve box, which is flanged and bolted to the water cylinder casting by through bolts, is a single casting, and is provided with heavy cast-in decks to receive the 3 suction and 3 discharge valves. All water compartments are separated by heavy cast partitions and large handholes are provided for ready access to the valves.

Unlike the water cylinders of the horizontal type, those in the vertical pumps have side openings instead of bottom openings.



SCRANTON VERTICAL DIVIDED WATER END TYPE TRIPLEX PLUNGER PUMP, WITH SINGLE-REDUCTION GEAR DRIVE

In general, the methods of drive employed in these pumps are similar to those in the horizontal units.

These pumps are made by The Scranton Pump Co.

Compound Pumps

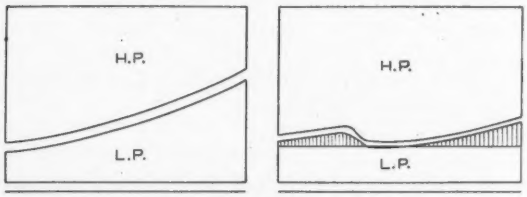
DIRECT-ACTING steam pumps with simple cylinders take steam during the entire stroke, which makes them extravagant in the use of steam compared to the actual amount of work done. To overcome this inherent difficulty, compounding is resorted to where high economy is essential and the exhaust steam cannot be used to advantage. Certain limitations, however, govern the economy of compounding, which should be considered before a compound pump is installed. Unless the boiler pressure is 80 lb. or greater, the additional initial expense of compounding will not be warranted unless the pump exhausts into a condenser, when boiler pressure of 50 lb. may be used with economy; the added expense of condensing equipment and complication of extra cylinders is hardly warranted on pumps with low-pressure cylinders smaller than 12 by 24 in.

Steam is admitted to the high-pressure cylinder during the entire length of stroke, so that it is not worked expansively in this cylinder. When the exhaust port of the high-pressure cylinder is opened, the pressure immediately drops to equalize the pressures in the exhaust side of the high-pressure cylinder, the connecting pipe, the low-pressure steam chest and clearance space. As the pistons move on their return stroke, the exhaust

pressure in the high-pressure cylinder falls in unison with the pressure in the low-pressure cylinder, this drop being in accordance with Boyle's law, for the area of the low-pressure piston being greater than that of the high-pressure, as the pistons advance the total volume increases and the steam expanding reduces in pressure.

Ratio of Compounding

One of the conditions necessary for the operation of direct-acting steam pumps is that the total force exerted by the steam pistons must at all times exceed that against the water piston.

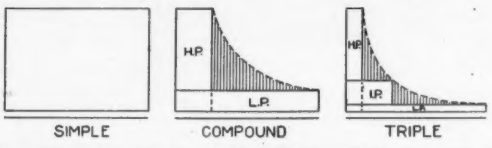


COMBINED DIAGRAM OF PLAIN COMPOUND PUMP
COMBINED DIAGRAM OF COMPOUND PUMP WITH CROSS-EXHAUST

Cross Exhaust

In order to overcome this difficulty to some extent a cross exhaust is sometimes used, consisting of a steam pipe connecting the steam chests of the low-pressure cylinders, with a valve in the pipe in order that the amount of steam passing from one side to the other may be regulated to give best results. By this means the steam from the high-pressure cylinder of one side of the pump exhausts into the steam chest of the low-pressure cylinder of the other side, when the piston in the latter has reached about ⅔ stroke. This raises the pressure at the time when it is most needed, but the cross-exhaust valve should never be opened more than enough to finish the stroke; the effect is clearly indicated by the accompanying diagram.

By carrying out the compounding idea further and using the cross-exhaust, manufacturers have developed triple-expansion pumps which have 3 instead of 2 cylinders on each side, the high-pressure cylinder taking steam direct from the boiler exhausting into the first intermediate space, and the intermediate cylinder with a cross-exhaust connection between intermediate cylinders; one of these cylinders exhausts in turn into the second



SIMPLE PUMP DIAGRAM; COMBINED SIMPLE DIAGRAM OF COMPOUND PUMP; COMBINED SIMPLE DIAGRAM OF TRIPLE CYLINDER PUMP

intermediate space and low-pressure cylinder which is connected by a cross-exhaust to the other low-pressure cylinder. Similar operation takes place on the other side.

The gain in economy due to compounding direct acting pumps is best represented by diagrams. A simple pump will have a steam diagram of rectangular shape; in this case all expansive energy of the steam is wasted by the pump. In the compound pump the combined diagram of the high and low-pressure cylinders is made up of 2 rectangles as illustrated, the gain in work due to compounding is represented by that portion of the low-pressure diagram extending to the right of the high-pressure diagram while the loss due to expansion between the high and low-pressure cylinders is represented by the shaded portion of the diagram.

In a similar manner the simple diagrams of a triple-expansion pump are combined which shows clearly that the shaded portion of the diagram is reduced by the addition of the third cylinder.

The percentage of gain by compounding varies from 20 to 35 per cent in noncondensing and 25 to 40 per cent in condensing pumps, depending upon the initial pressure and ratio of expansion.

Effect of Condenser

Considerable gain in economy of steam can be obtained by condensing the exhaust, for the steam cylinders can be made smaller in diameter for the same size water cylinder and pressure. The percentage of gain depends upon the boiler pressure but the pump may be designed for an equivalent of 10 lb. greater steam pressure when it is to be run condensing than when noncondensing; that is, adding a condenser is equivalent to raising the steam pressure 10 lb. on a simple pump; when a compound or triple expansion pump is used, adding a condenser is equivalent to increasing the steam pressure in the low-pressure cylinder 10 lb. without changing that in high-pressure cylinder.

CYLINDER RATIOS OF COMMERCIAL PUMPS

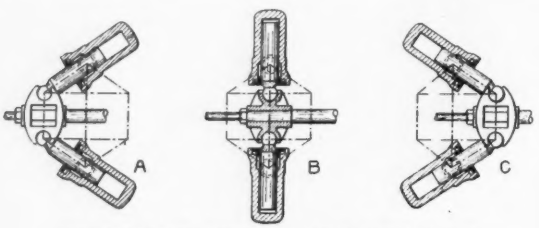
Diam.	Ratio of Piston Areas				
H. P.	2 to 1	2½ to 1	3 to 1	3½ to 1	4 to 1
Cyl.	Diam. L. P. Cyl.				
6	8½	9½	10½	11	12
7	10	11	12	13	14
8	11	12½	14	15	16
9	13	14	15½	17	18
10	14	16	17	19	20
11	15½	17½	19	20½	22
12	17	19	21	22½	24
13	18½	20½	22½	24½	26
14	20	22	24	26	28
15	21	24	26	28	30
16	23½	25	28	30	32
17	24	27	29½	32	34
18	25½	28½	31	33½	36
19	27	30	33	35½	38
20	28	31½	34½	37½	40
21	30	33	36½	39	42
22	31	35	38	41	44
23	32½	36½	40	43	46
24	34	38	41½	45	48

Another means of reducing steam consumption is by the use of steam jackets which have proved to be of advantage particularly on the intermediate and low-pressure cylinders, while it is usually considered sufficient to cover the high-pressure cylinder with insulating material.

While the majority of compound pumps are of the duplex type, there are several makes of the simplex type. The arrangement of cylinders is in tandem; for although cross compounding has been tried out, the method proved impractical as the variation in the action of the 2 cylinders gave unsatisfactory results. In the smaller sizes it is common practice to attach the high-pressure cylinder to the outside head of the low-pressure, overhung by means of a yoke. In larger sizes both cylinders are supported by pedestals or feet and the arrangement of

cylinders is frequently reversed; the various arrangements may be seen in the commercial descriptions which follow.

The valve gear may be either the simplex or duplex type similar in essential respects to those employed on simple pumps, with the addition of connections for operating high and low-pressure valves on each side of the pump in unison. In some triple-expansion pumps, however, cutoff valves are employed by means of which it is possible to regulate the pressure so that the piston will not strike the head, without using the cross-exhaust.

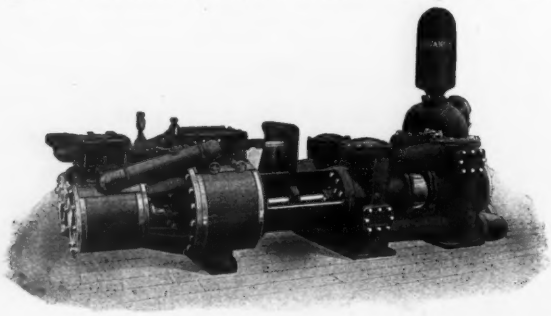


COMPENSATOR USED ON HIGH DUTY PUMP

Also in some of the largest pumps rotary valves are employed which give more direct steam ports, reduce friction and allow of convenient arrangement of gear.

Use of Compensator

From what has been stated previously it will be apparent that the great difficulty in securing high economy in direct acting pumps which are not equipped with flywheels has been to devise some means for working the steam expansively, for in neither the compound nor the triple cylinder (commonly called triple expansion) pumps does the steam work expansively as in a cutoff engine. The feature which has been lacking is a means



ADVANCE OUTSIDE CENTER PACKED COMPOUND PLUNGER PUMP

for taking up energy during the first part of the stroke to be given up during the latter part. This need was met by J. D. Davies who patented, in 1881, what are called compensating rams, now used in the construction of Worthington high-duty pumps. These consists of 2 cylinders which oscillate on trunnions. Fitting the cylinders are plungers which are attached by pins to the crosshead on the piston rod; the compensating cylinders are placed on opposite sides of the piston rod and so situated that as the main piston of the pump starts its stroke the plungers of the compensating device are forced into their cylinders until the pump has reached mid-stroke, when the plungers are forced out of their cylinders during the rest of the pump stroke. The cylinders are filled with water or oil under pressure connected through the trunnions with the discharge of the pump or some container which will absorb and give out pressure. Thus, during the first part of the stroke the compensator is absorbing energy, and during the latter part it is giving energy to the piston rod. This device has permitted the use of steam expansively, cutoff taking place at the most economical part of the stroke. It is used on both compound and triple-expansion pumps.

Pipe Sizes

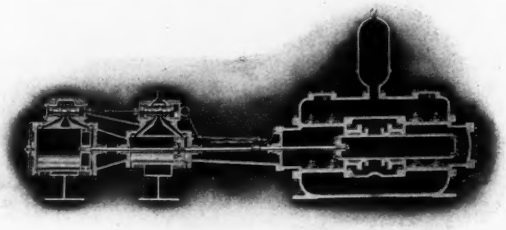
Water pipes for pumps, according to Nickel, should be of such size that the velocity on the suction side will not exceed 240 ft. a minute and on the discharge side 300 ft. is the limiting practical value. The expressions for pipe diameters is as follows:

Suction diameter $= \sqrt{0.1G}$

Discharge diameter $= \sqrt{0.08G}$

where G is the number of gallons pumped per minute.

Steam pipes should be of such size that the velocity will not exceed 6000 ft. a minute while the maximum



SECTIONAL VIEW AMERICAN COMPOUND OUTSIDE CENTER PACKED PLUNGER PUMP

practical speed in the exhaust pipe is 4000 ft. a minute.

Inasmuch as steam is used at full pressure during the entire stroke of the pump, the following proportion holds:

$$\frac{\text{Area of steam cylinder}}{\text{Area of steam pipe}} = \frac{\text{velocity of steam in pipe}}{\text{Piston speed in ft. per min.}}$$

or $\dfrac{D^2}{d^2} = \dfrac{v}{p.s.}$

where D = diameter of steam cylinder, d = diameter of steam pipe, v = velocity of steam in pipe, and p. s. = speed of the piston in feet per minute.

This proportion holds good for both steam and water piping of simplex pumps; when duplex pumps are used, the area of the pipe must be double that obtained by the above proportion.

Advance Outside Center Packed Compound Plunger Pump

In the design of pump here illustrated, made by Advance Pump & Condenser Co., is embodied the general features of the high-pressure compound pumps made by this company, which are suitable for boiler feeding and general service work, delivering against pressures as high as 250 lb. These pumps are built to operate condensing or noncondensing, and different sizes of steam and water ends, as well as special construction can be had.

Compound steam cylinders may be fitted with specially constructed steam throttle valves so live steam

may be admitted at boiler pressure to the low-pressure cylinder. In the design of the water end the cylinders are made separately and united with cross-over suction and delivery pipes.

American Compound Pump

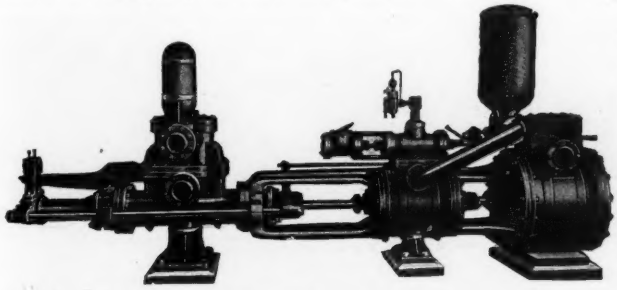
Compound pumps made by the American Steam Pump Co. are equipped with steam valves of the balanced piston type governed by an auxiliary valve in the high-pressure steam chest, which is mechanically actuated by a lever connected to the piston rod of the pump. These pumps differ from the simplex pumps, described elsewhere in this issue, only in the addition of another yoke and cylinder mounted on a separate base. The steam pistons are connected by a steel rod. The high-pressure and low-pressure steam valves are connected by a bronze rod with turnbuckle adjustment. The low-pressure valve is similar to the high-pressure valve and it is operated directly by it.

Yough Compound Steam Pump

In the illustration is shown the plunger type of Yough compound steam pump, made by Boyts, Porter & Co., with outside end-packed plungers. The pump is fitted with a condenser chamber and cataract valves. When desired the steam end is lagged. The steam valve is the same as that used on the simplex pump, made by this company, described on another page of this issue and is especially adapted to this class of work as it allows some expansion in the high-pressure cylinder.

Buffalo Compound Duplex Pumping Engine

The general features of the compound duplex pumping engine made by the Buffalo Steam Pump Co., are shown in the accompanying illustration in which it will be observed that the high-pressure cylinder is outboard. The steam valve chests are in line so that a straight stem with rigid coupling between cylinders is used to shift the slide valves. A by-pass is provided on these pumps so that live steam may be used in the low-pressure cylinders in emergency or when fire pressure is desired.



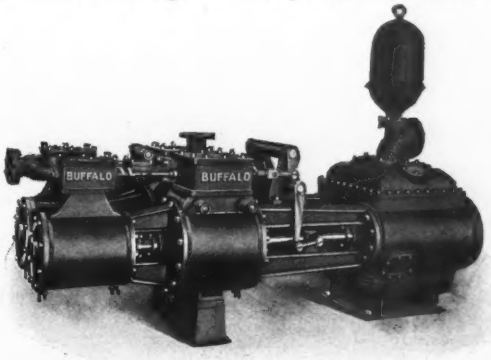
YOUGH COMPOUND STEAM PUMP WITH OUTSIDE PACKED PLUNGER

The steam ends are fitted with a cross exhaust valve for equalizing pressure in the 2 low-pressure cylinders, thus insuring equal stroke and speeds on both sides of the pump.

Cameron Single Compound Pump

The single compound pump, manufactured by A. S. Cameron Steam Pump Wks., is designed without outside valve gears. The same mechanism is employed here as in the simple pump, which is described elsewhere in this issue. It is claimed that the whole steam valve movement is more positive than in a simple pump since the high-pressure steam chest plunger is freer to move and that of the low-pressure cylinder has an almost irresistible force acting on it at the moment of reversal.

Other features of the pump are short pipe connections between the high and low-pressure cylinders, small clearance spaces, thereby reducing the initial pressure in the expansion cylinder and reducing the terminal pressure which has an important influence in the determination of the amount of resistance which can be overcome, that is, the amount of work accomplished.

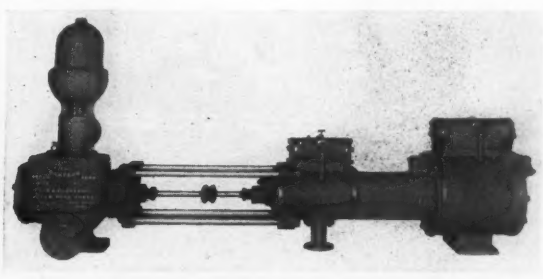


BUFFALO COMPOUND PISTON PATTERN DUPLEX PUMPING ENGINE

Davidson Compound Pump

In the illustrations are shown the compound pump made by the M. T. Davidson Co., especially for boiler feeding, waterworks and situations where it is desired to remove large quantities of water economically. This is of the simplex type with the high-pressure steam cylinder placed outboard, the type of steam valve gear being the special design of this company, which is described in connection with the simplex pump.

For elevator service the compound separable duplex type is the special design of this company. This consists of a pair of Davidson single-cylinder elevator pumps arranged to operate as a duplex machine, either side of which may be shut down and the other side run as a single cylinder, double-acting pump. This change can be made instantly and without interruption to the service. This arrangement gives the advantage of being able to use the duplex machine for full load and the single machine for light loads.



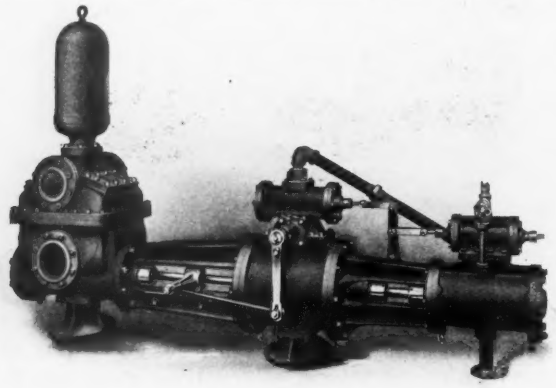
CAMERON SINGLE COMPOUND PUMP

Some of the advantages claimed for this machine are a properly proportioned steam end to do the work, starting promptly when regulators act, a positive acting

valve motion which does not short-stroke and cause excessive clearance in the steam end, long stroke, tight water pistons fitted with hydraulic leather packing and few moving parts, which are adjustable to compensate for wear.

Dean Bros. Compound Hydraulic Pressure Pumps

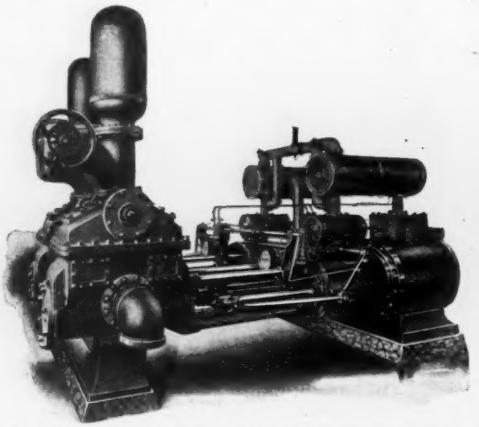
Compound hydraulic pressure pumps made by Dean Bros. Steam Pump Wks., employ semi-rotary type of valve gear, giving better cut-off and reducing friction to a minimum. The valve gear and steam chest are located beneath the cylinders, making the cylinders self



DAVIDSON COMPOUND PUMP

draining. The high-pressure cylinder is placed between the low-pressure cylinder and pump, eliminating trouble between the high- and low-pressure cylinders.

Frames, between the steam and water ends, are of the bar type, an excellent form for insuring absolute rigidity. This type of frame gives accessibility to the glands and valve gear.



DAVIDSON COMPOUND SEPARABLE DUPLEX PUMP

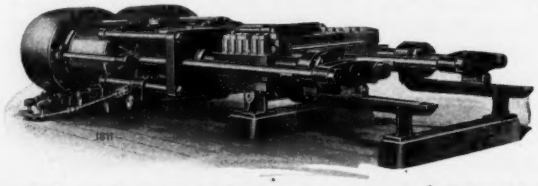
Smaller sizes of pumps are made with plain steam slide valves, with one common valve stem operating both high- and low-pressure cylinders. These compound steam ends can be applied to all types of water ends.

Deane of Holyoke Compound Duplex Pump

The Deane Steam Pump Co. compound duplex pumps for general service differ but little from the simple duplex pumps made by this company, except for the addition of steam cylinders fastened by yokes to those of the regular duplex pumps. The general arrangement will be seen in the accompanying illustration. By this arrangement steam is used expansively and it is claimed that the steam consumption is reduced ⅓ from that of simple pumps. These pumps are built in all proportions of cylinders which are best suited to the service they are designed to perform.

Epping-Carpenter Pressure Pattern Compound Pump

Valve gear used with the Epping-Carpenter pressure pattern compound pump is of the duplex type. Lugs on the piston rods have slots on both sides in which the forks of the rocker arms work, transmitting the motion



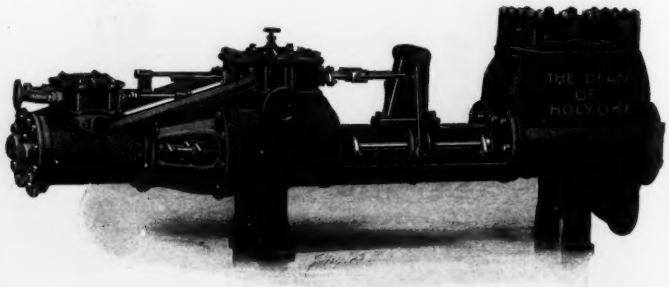
COMPOUND STEAM END USED ON DEAN BROS.' HYDRAULIC PRESSURE PUMP

to the valve rods through connecting links. Lost motion is secured by providing sliding sleeves at the ends of the link, which are attached to the short arms of the rockers.

Steam cylinders are arranged with the low-pressure outboard and by this arrangement the valve rod of the low-pressure cylinder is carried in guide bearings over the high-pressure steam chest. The high-pressure valve is worked from an offset lug on the low-pressure valve rod. The illustration shows the pump equipped with balanced piston valves and also cushion valves in the low-pressure cylinder to prevent the piston from striking the head.

Fairbanks-Morse Compound Duplex Plunger Pump

For waterworks and general service where economy of steam is an important item, the type of pump illustrated herewith, made by Fairbanks-Morse & Co., is well



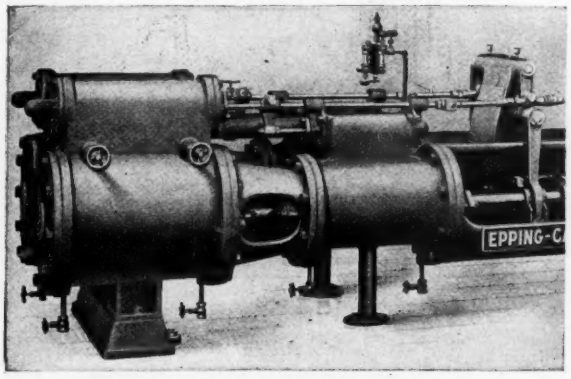
DEANE COMPOUND DUPLEX PUMP FOR GENERAL SERVICE

adapted. The valve area in these pumps being large, and the arrangement of the water valves such as will give a direct course for the water through the pump, they may be operated at maximum speed without undue shock or vibration.

A bypass can be fitted to these pumps whereby live steam can be admitted direct to the low-pressure cylinder to give the steam end more power, enabling the water pressure to be increased for use in case of fire or at other times when desired.

Gardner Duplex Compound Steam Pumps

Compound pumps made by The Gardner Governor Co., are an example of the type having overhung high-pressure cylinders. These are attached to the low-pressure cylinders by cradles or yokes, giving ample space for packing the piston rod. The steam valve chests are placed in line so that the valve rod of the high-pressure cylinder is attached to an extension of the low-pressure rod by means of a turnbuckle. Cushion valves are

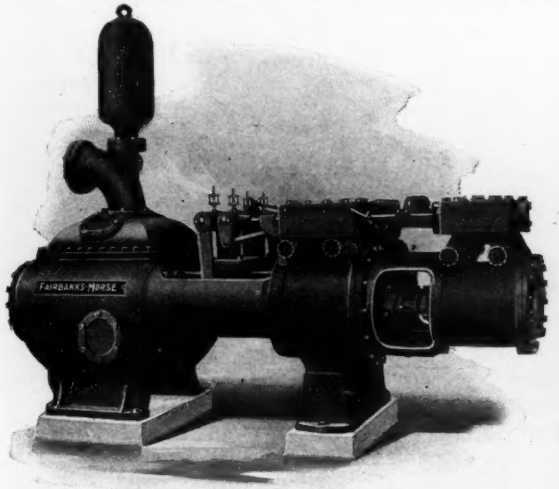


EPPING-CARPENTER COMPOUND STEAM END

placed in the low-pressure cylinder. When desired, these pumps may be piped so as to bypass the high-pressure cylinder, admitting high-pressure steam directly to the low-pressure cylinder, an arrangement which is sometimes convenient when the pump is used for general purposes. This pump is illustrated on page 1.

Smith-Vaile Compound Pumping Engines

For handling large quantities of water economically, Smith-Vaile compound pumping engines, made by Platt Iron Works, have met with success. These pumps



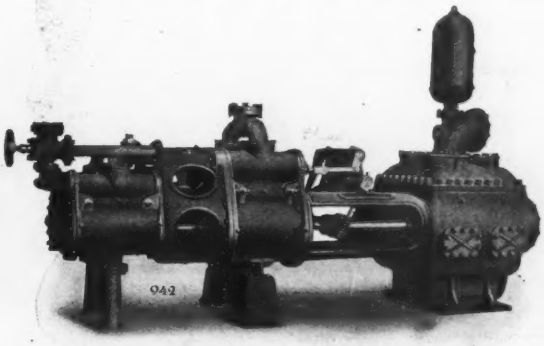
FAIRBANKS-MORSE COMPOUND DUPLEX PLUNGER PATTERN PUMP

are made in various combinations to suit all requirements for pumping water for all purposes.

The construction throughout is massive yet simple, and all working parts are easily accessible and ample space is allowed for packing the stuffing boxes. When desired, a live steam switch valve may be provided for the admission of steam at boiler pressure direct into the low-pressure cylinders, converting the engine into a high-pressure pump for fire service.

Scranton Compound Duplex Piston Pump

Compound Duplex piston pump made by The Scranton Pump Co., are designed for service at 150 lb. pressure or less. The object of compounding is, of course, to economize on steam, and in this pump to carry the idea further, the steam cylinders are covered

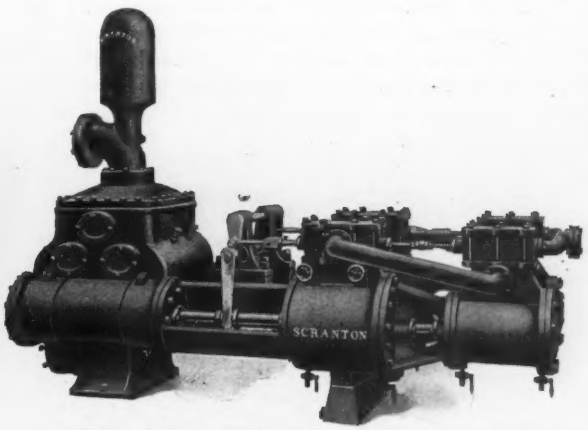


SMITH-VAILE COMPOUND DUPLEX PUMPING ENGINE, PISTON VALVE TYPE

with noncondensing lagging held in place by iron covers, thus reducing cylinder condensation. The steam cylinders are provided with a simpling device so that the pump may be started with live steam in all cylinders. In the standard type slide valves are used in the steam ends, but piston valves may be furnished if desired.

Burnham Compound Steam Pumps

The Burnham compound pump is an arrangement the water end of which is essentially the same as is used on the various designs of simplex pumps made by the Union Steam Pump Co., while the steam end consists



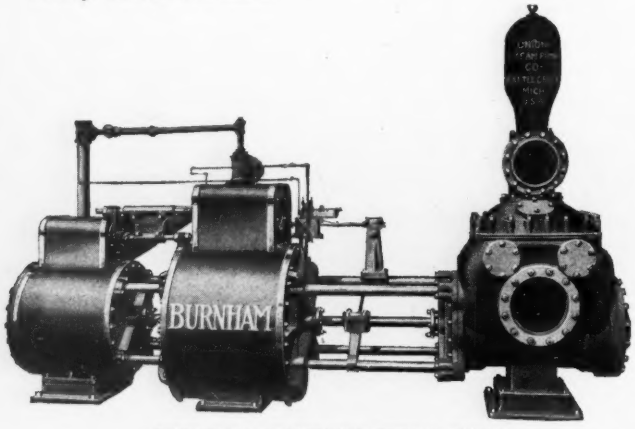
THE SCRANTON COMPOUND DUPLEX PISTON PUMP

of 2 cylinders in tandem, the valves of which are operated by a mechanism similar to that employed in the simplex pumps.

This type of pump is especially adapted for elevator service since it is economical in steam consumption due to the fact that the steam is used expansively, and owing to the small amount of clearance space in the cylinders.

Worthington Compound Boiler Feed Pumps

For pressures up to 300 lb. where economy of steam is important, Henry R. Worthington installs a compound pot valve pressure boiler feed pump with packed plunger. The pump has a duplex valve gear with slide valves except where extra refinements are required or superheated steam is employed, then piston or semi-rotary valves are used.

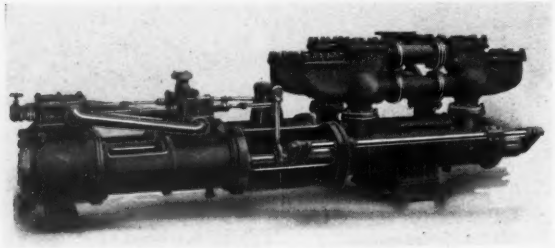


BURNHAM COMPOUND STEAM PUMP

The pump is supported on foot pieces under the low-pressure steam and water cylinders with the high-pressure cylinders suspended between them, plenty of space being left between cylinders for repacking piston rods The valve chests are in line so that the valve rods are connected by a coupling. Cushion valves are used on the low-pressure cylinder and a cross-over connection is made between the low-pressure valve chests.

Rotary Pumps

ROTARY pumps are used most extensively in industries where thick or heavy liquids are handled, also liquids containing solids such as pulp, malt and similar materials. They are used quite extensively for fire pumps in factories, as they are capable of giving a positive pressure against variable heads and their simplicity makes them reliable even after long periods of

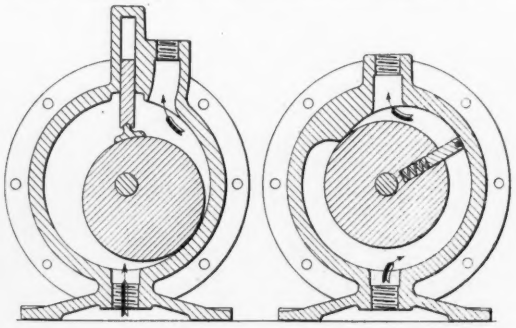


WORTHINGTON COMPOUND POT VALVE BOILER FEED PUMP

idleness. There is an advantage in the rotating over the reciprocating motion in moving the liquid, for with the latter inertia must be overcome at the beginning and end of each stroke and the liquid is discharged in a pulsating stream which may cause trouble in pipe lines. In the rotary pump these difficulties are avoided.

In these pumps, the liquid is moved by catching it between the lobes of revolving impellers and the casing of the pump, and sweeping it around from the suction to the discharge opening; its return is prevented by a butment or the lobes and cylinders at the center, depending upon the type of pump.

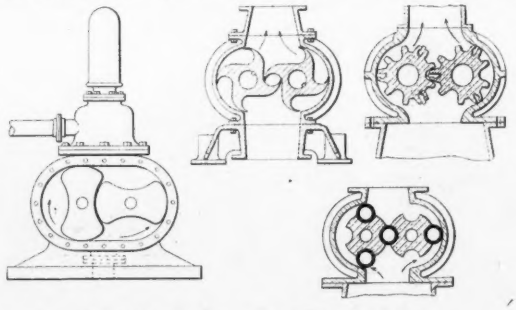
There are, in general, 3 classes of rotary pumps: first, those having a movable butment, second, those having a stationary butment, but movable blade, and third, those having 2 impellers with intermeshing lobes.



ROTARY PUMP WITH MOVABLE BUTMENT
ROTARY PUMP WITH MOVABLE BLADE

In the first class, the impeller is cylindrical but revolves around an eccentric axis through the center of the casing. The butment slides on the surface of the impeller moving in or out, under the influence of a spring, according to the position of the impeller. The discharge is pulsating and check valves are required to prevent the liquid from returning during the time the long radius of the impeller is passing the butment and the suction opening.

When a movable blade on the impeller is used, the axis of the driving shaft coincides with the center of the impeller, but the case is set eccentric or is of a special form, giving similar results. The action of this class



ROTARY PUMPS WITH 2 IMPELLERS

is similar to that of the first mentioned, but in some makes 2 or more blades are used which give a more uniform rate of discharge and eliminate the use of check valves.

In those pumps having 2 impellers, the case is made semi-cylindrical at each side with a driving shaft at the center of each semi-cylinder. To the shafts are attached the impellers, which are usually made with cycloidal lobes around the periphery. The number of these lobes ranges from 2 up, depending upon the ideas of the designer. In this class, the intermeshing of the impeller lobes at the center forms the butment to prevent the liquid from returning to the suction side; after the lobes have passed the intermeshing point, a partial vacu-

um is formed into which the liquid is drawn from the suction pipe, and it is then swept around to the discharge by the following lobe.

As stated above, the lobes are usually cycloidal in shape, but this is not always the case. In some makes, the form of the lobe is helical to the outer diameter, the return being a circular curve. The simplest type of impeller consists of a cylinder with 4 semi-circular

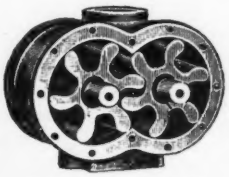
POWER REQUIRED, SPEED, CAPACITY AND PRESSURE OF SCREW PUMPS

Low Pressure				High Pressure			
Horsepower of Motor	Revolutions per Minute	Gallons per Minute	Maximum Pressure in Lbs. per Square Inch	Horsepower of Motor	Revolutions per Minute	Gallons per Minute	Maximum Pressure in Lbs. per Square Inch
2	1200	44	40	5	1200	32	150
3	1200	36	70	6	1200	30	175
4	1200	52	80	10	1300	65	150
5	1200	50	100	12	1300	65	175
6½	1200	45	120	15	1200	95	150
10	1200	145	60	18	1200	90	175
12	1200	141	75	17	1300	110	150
15	1200	135	95	20	1300	105	175
20	1100	230	90	25	1200	160	150
25	1100	215	120	30	1200	145	175

grooves cut in the surface parallel to the axis. In 2 of these, which are diametrically opposite, are bolted circular pipes, which serve the purpose of the lobes and mesh into the grooves of the companion impeller as the surfaces come together at the center.

Other forms of impellers are shown in the descriptions which follows, but the principle of operation is that outlined above. The discharge from 2-impeller pumps is slightly pulsating when a small number of lobes is employed, but by increasing the number the discharge is almost uniform and no valves are needed for successful operation; a check valve is desirable, however, in the discharge line, for should the power be removed

BARNES ROTARY FORCE PUMP



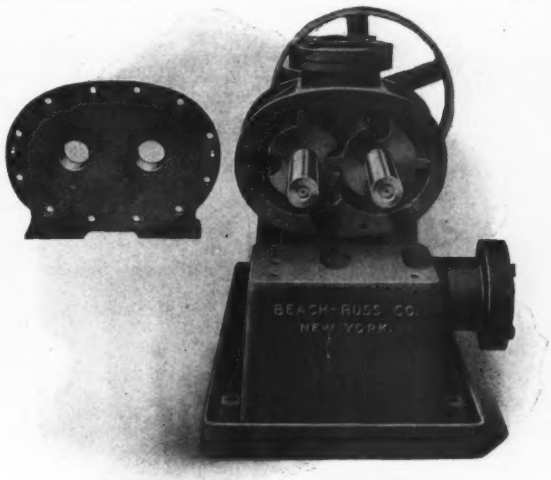
VIEW OF BUFFALO ROTARY FORCE PUMP WITH HEAD REMOVED

from the pump, the pressure in the discharge would run the pump as a motor, were some means not provided for preventing the return of the liquid through the pump.

Rotary pumps, when properly designed, are simple and reliable, but the percentage of slip is comparatively high, and owing to wear, leakage is likely to become excessive, particularly at high heads after the pump has been in operation for a time.

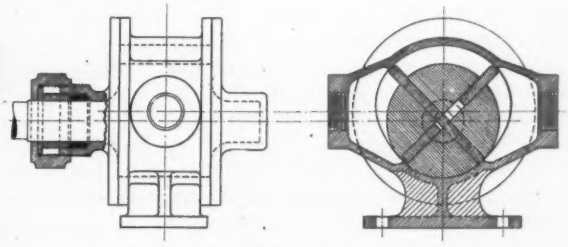
Screw pumps may be classed as special rotaries; the principle of operation is quite different, but the class of work to which they are adapted is similar, although screw pumps may be used to advantage where higher heads are encountered. Both are positive displacement pumps.

Pumps of this class consist of screws that act as pistons in propelling the water, being arranged in pairs



INTERIOR VIEW OF BEACH-RUSS ROTARY PUMP

so that the threads of one screw project to the bottom of the space between the threads of the companion screw. The screw threads have flat tops and peculiarly undercut sides, the width of the face and the base of the thread being half the pitch. The water is caught between threads at the suction end of the pump and propelled to the discharge in a direction parallel to the shaft. By careful design and workmanship, these pumps can be made to operate with little friction and by increasing the length of the propeller screws, leakage can be reduced to an inappreciable amount, even under high heads. One of the distinct features of screw pumps is that the propeller shafts may be run at high speeds, making them adaptable for direct connection to motors



THE CENTURY ROTARY PUMP IN CROSS SECTION

or turbines. In the accompanying table are given the power required, speed, capacity and pressure of one make of screw pumps.

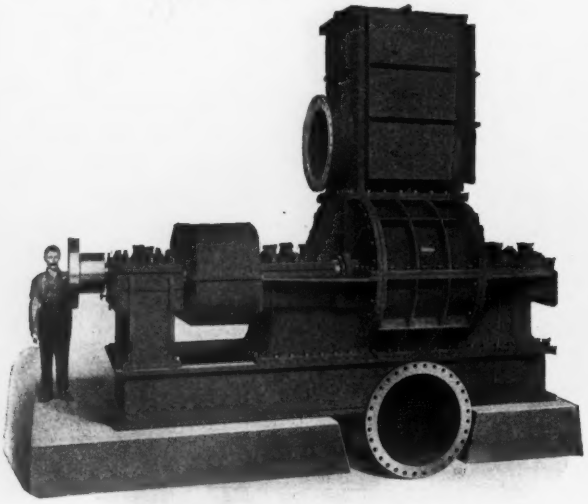
Barnes Rotary Force Pump

Belt driven rotary force pumps, made by the Barnes Mfg. Co., are of the 2-impeller type, having intermeshing cams. The pump with belt pulleys is mounted on an iron frame, making it easy to install in places where

space is limited. The spout is adjustable to any position desired and, by removing the cap from the top and placing it on the end of the spout, the pump will discharge vertically.

Beach-Russ Return Line Vacuum Pumps

Beach-Russ vacuum pumps are designed to meet the requirements of return line vacuum heating systems. The pump runs noiseless, withdrawing the condensation and air from the heating system; it separates the air from the water and returns the condensation to the boiler under 10 lb. pressure, or condensation can be discharged into a receiving tank and then to boiler, as conditions will allow. The illustration shows the pump has 2 impellers of a simple type; these are kept in proper relation to each other by a pair of gear wheels attached to the shafts between the pump and the pulley.



CONNERSVILLE CYCLOIDAL PUMP, DESIGNED FOR CIRCULATING PURPOSES

Buffalo Rotary Force Pump

The rotary force pump made by the Buffalo Steam Pump Co. is designed for a lift and force 60 ft. from supply to the point of delivery with the pump not more than 20 ft. above the supply. The illustration shows the arrangement and number of cams which will give to the water a uniform rate of discharge. These pumps are suitable for a wide variety of service, and are manufactured in sizes from 1½ to 2½ in.

The Century Rotary Pump

Rotary pumps manufactured by The Century Pump Co. consist mainly of a cylinder, 2 heads, a rotating piston and 4 flat buckets or blades which slide in and out of 4 slots in the piston. Set eccentrically to and parallel with the center line of the cylinder, the rotating piston hangs close to the bottom of the cylinder and its journals are supported in bearings contained in the heads. The fluid being pumped is drawn into the cylinder by the vacuum formed behind the blades in their upward sweep, and forced out through the discharge opening by the fronts of the blades. The cylinder head through which the piston shaft protrudes is provided with a stuffing box gland and nut. This arrangement permits the pump to run in either direction without the friction of the packing on the shaft either tightening or loosening the stuffing box nut.

Connersville Cycloidal Pump

The Connersville Blower Co. manufactures cycloidal pumps of the rotary type, each being provided with 2 impellers which have the form of the cycloid with either 2 or 3 lobes. These impellers mesh together but do not come in contact with each other, the shafts being driven by intermeshing gears so that the surfaces of the impellers are not subject to wear. These pumps are especially suitable for pumping water for irrigation, filtration reservoirs, cooling towers, condensers, circulating work, etc., also for handling liquids such as tar, oils and ammonia, and when especially constructed may be used for creating high or low vacuums.

One particular advantage claimed for this type of pump is that with it air or gases and water can be handled simultaneously. The discharge from the pump is continuous, but not uniform, and in order to provide for the variation in flow, air chambers are placed on both suction and discharge sides.

Deming Rotary Force Pump

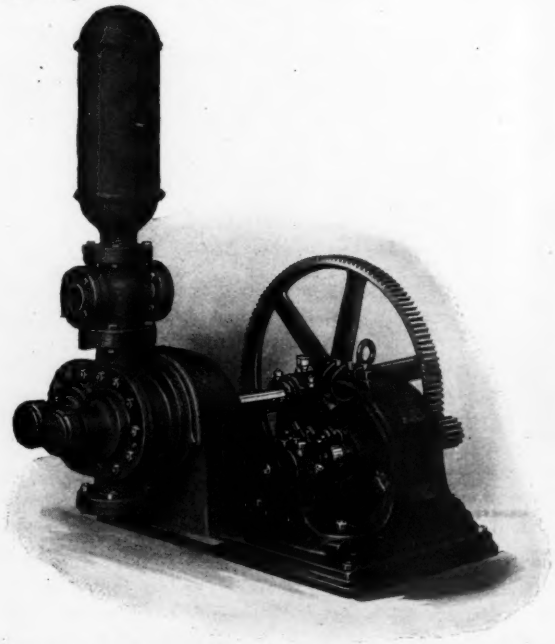
Power rotary pumps are manufactured by The Deming Co. for both heavy and light service, being designed for pressures as high as 50 lb. They have a compensating gear drive for the cam which permits foreign substances such as small pieces of wood, leather, etc., to pass through without injury to the pump. These pumps are especially suitable for handling oil in refineries and mills. When used for pumping water it is essential that the water be entirely free from any gritty substances. They can be operated by belts from any source, or can be fitted with extended case and gearing connected for slow speed electric motor as illustrated herewith.

General Condenser Company's Rotary Air Pump

This pump consists of 3 main parts—the body, rotor and gliders. Briefly the operation is as follows:

The main shaft A is keyed to and drives the rotor B, the opposite end of the rotor being made separate in order to permit of easy access to the interior. These parts turn as a unit on ball bearings C about the center line X-X. This rotor is eccentric to center line Y-Y of the body D, the distance between these centers determining the displacement of the pump. The revolving rotor is at all times tangent to the body liner F at the point G, wear at this point being relieved by a film of light oil running the length of the rotor and maintaining an air-tight fit at this point. The rotor is fitted with 2 gliders or wings H, which are driven by the rotor through nuts M, set into the rotor. In order to eliminate the wear between gliders and body liner, due to centrifugal pressure, these gliders are fastened to and rotate independently of each other about a crank shaft L, the center line of this shaft being concentric with that of the body. This shaft is stationary, being rigidly fixed at one end in cover P, and is supported in ball bearings N carried by the revolving rotor B. The dotted lines show relative positions of gliders, rotor and nuts at which compression is just commencing. In this position the glider H_1 is just starting to compress the

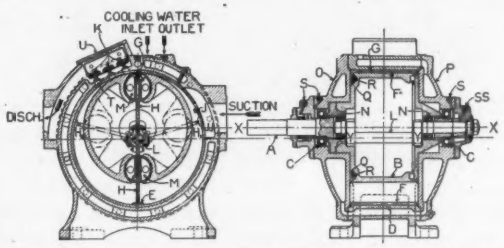
air between itself and the glider H_2 at the same time drawing in air behind it until H_2, moving around to JJ, cuts off this suction, which in turn is discharged through K. The arrangement of rotor and gliders on eccentric centers causes a slight angular movement of the glides in reference to the center of the rotor. The nuts M are therefore arranged to turn in their bearings and to allow the rotor as a whole to have a reciprocating action on the gliders.



DEMING POWER ROTARY FORCE PUMP WITH DIRECT MOTOR DRIVE

Hunt Rotary Fire Pump

The principle of operation of the Hunt rotary fire pump, made by Rodney Hunt Machine Co., is that of intermeshing cams enclosed in a water-tight case, thus giving a positive discharge of water against the required pressure at any speed desired. The pump is designed to fulfill requirements of the specifications of



SECTIONAL ELEVATIONS OF THE GENERAL CONDENSER CO.'S ROTARY AIR PUMP

the Associated Factory Mutual Fire Insurance Co.

It will be noted in the illustration that this pump is compact, yet all parts are accessible. The starting valve, the pressure and pop relief valves, sight cone discharge and oil gage are all in easy reach or plain sight. The entire base below the line indicating where the top covers of the bearings come off, is cast in one piece, the inside being hollow, forming an oil reservoir, supplying bearings as well as gears.

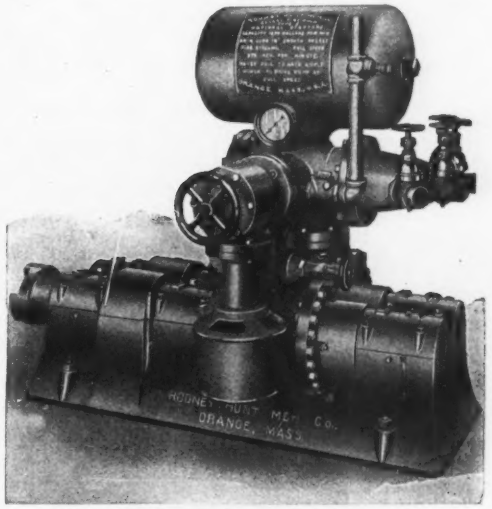
The Lammert & Mann Rotary Vacuum Pump

The Lammert & Mann rotary vacuum pump is designed for work such as canning, preserving, milking, etc., where an even high vacuum with a minimum amount of attention is required. To avoid wear and leakage, past the lobes of the rotating element, the working parts are kept splattered with oil by automatic oilers. These pumps are made in several sizes and styles to meet the various demands of service. The smaller light service pumps, which are capable of maintaining a vacuum of 26 in. of mercury are air cooled, having large radiating surface for that purpose. These are intended for intermittent service only where the work is not too exacting. The larger pumps are water cooled and are capable of maintaining continuously a vacuum of 27 in.

In some styles the tandem arrangement is employed, and in this case they are water cooled and will maintain a vacuum within ½ in. of the barometer.

Lobee Rotary Pumps

Rotary pumps manufactured by the Lobee Pump & Machinery Co., consist of shell and heads, valves and piston. The shell and the foot upon which it rests is a one-piece casting, making the shell rigid and preventing



HUNT ROTARY FIRE PUMP

any strain being thrown on the piston or shaft. The foot is secured with bolts to an iron sub-base. The heads of the shell and the flanges of the suction and discharge openings are put on with through bolts and nuts.

Four valves are employed which are formed in 2 pairs, one valve having 2 parallel arms provided with longitudinal ribs or tongues and the other valve having 2 parallel arms provided with longitudinal depressions or grooves, forming side ways in which the ribs or tongues upon the arms of the other valve seat and travel and pass back and forth through the slots in the piston during operation and do the pumping.

By this arrangement the valves are always kept in position to work, are self-adjusting and are automatically kept against the periphery of the shell and create the vacuum, and are like 2 solid valves.

The piston which operates and carries the valve, and through which they are slid back and forth during their operation is made solid and wide at both ends, which prevents it from breaking, in case any foreign substances get into the pump too large to pass the valves, and the shaft is made of steel. One of the many good features of this pump is the arrangement of a hand hole plate, making it easy of access without disconnecting the piping or dismounting the whole pump.

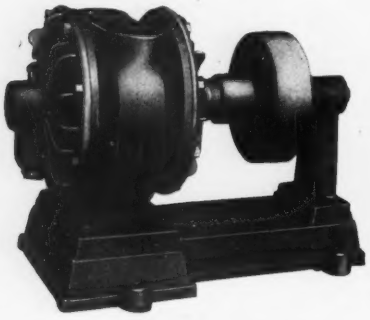
Quimby Screw Pump

The general form and construction of the Quimby screw pump is illustrated herewith. The 4 screws that act as pistons in propelling the water are mounted in pairs on parallel shafts and are so arranged that in each pair the threads of one screw projects to the bottom of the space between the threads of the opposite screw. The screw threads have flat faces and peculiarly undercut sides, the width of the face and base of the thread being one-half the pitch. The pump cylinder takes the perimeters of the threads as shown in the end view.

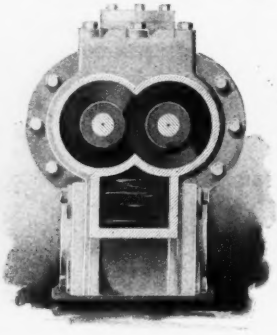
Suction connection is shown at S, and opens into a chamber underneath the pump cylinder. The suction liquid passes through this chamber to the 2 ends of the cylinder and is forced from the 2 ends toward the center by the action of the 2 pairs of intermeshing threads. The discharge being in the middle of the top of the cylinder as shown at D. The power to drive the pump is applied to one of the shafts and the second shaft is driven by means of a pair of gears.

The only packing employed is in the stuffing boxes where the 2 shafts pass through the cylinder heads, and as these stuffing boxes are on the suction side of the pump the strain on the packing is slight.

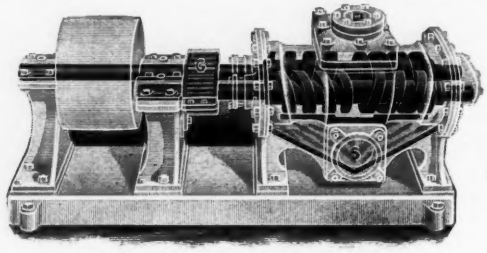
These pumps are made by Wm. E. Quimby and are adaptable for direct connection to a motor or belt-drive.



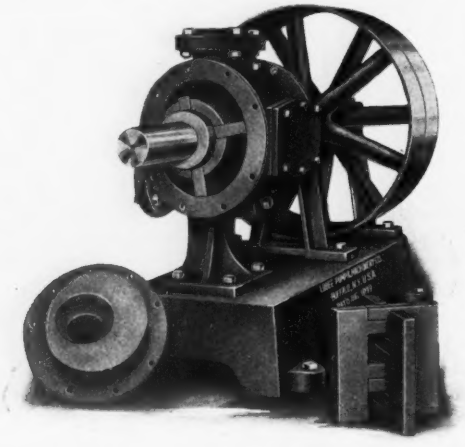
AIR COOLED SINGLE STAGE LAMMERT & MANN ROTARY PUMP



END VIEW OF QUIMBY SCREW PUMP



QUIMBY SCREW PUMP



INTERIOR VIEW OF LOBEE ROTARY PUMP

Roots Vacuum Pump

Vacuum pumps made by P. H. & F. M. Roots Co., are of the rotary type, built especially for use in paper mills where air and water have to be handled by the same pump. Under these conditions it is made for down discharge wherever possible. Where the water has to be discharged into a collecting box for re-use and the pump cannot be set high enough to allow the water to flow by gravity from the bottom a spray discharge device has been designed which allows the pump to be operated with top discharge, the water flowing from the top of the pump by gravity to the collecting box. A stuffing box with solid gland using fiber packing is used effectively for preventing leaks around the shaft.

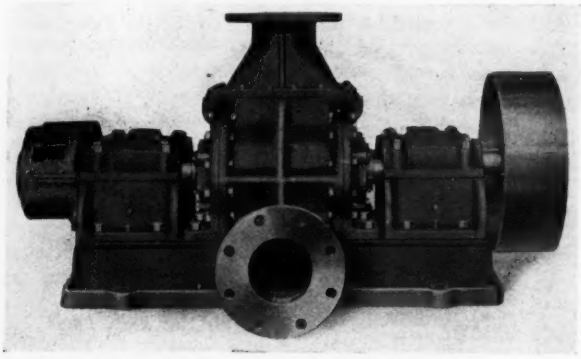
Impellers used in vacuum pumps are of the 2-lobe pattern built up from solid forgings to which the cast-iron lobes are bolted, except when straight line impellers are used, these being constructed of cast iron and pressed on the shaft by hydrostatic pressure. Impellers used on pump for water only are of the straight line, built up pattern.

Pratt Rotrex Vacuum Pumps

When it is desired to drive the vacuum pump together with the circulating pump and hot well pump, from a single engine, turbine or motor, the Rotrex pump, a product of the C. H. Wheeler Mfg. Co., lends itself excellently to such an arrangement. The cylindrical rotor is mounted eccentrically on a shaft supported in out-board bearings. An oscillating cam operated from the rotor shaft by means of external crank and connecting rod separates the suction and discharge sides of the pump cylinder and follows the motion of the rotor with a small clearance. The rotor is so adjusted as to maintain, during its entire rotation, a close clearance with the inside of the air cylinder. Air is drawn through the intake at the lower right and discharged through the valves on the V-shaped deck above the cam.

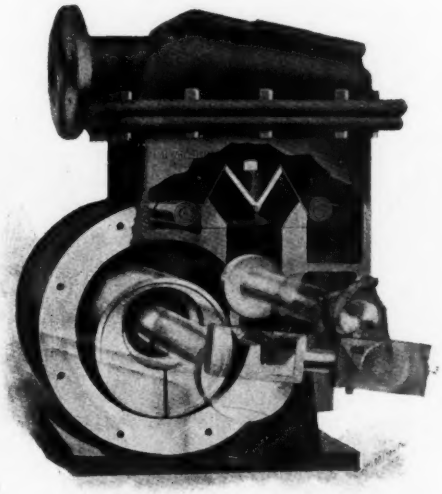
Freedom from leakage is assured because all clearances are water-sealed.

A special advantage of the Rotrex pump consists in the possibility of having the suction space in the cylinder open to the condenser all the time so that the action of the pump does not depend upon its producing, during a part of the stroke, a vacuum higher than that



APPLICATION OF ROOTS VACUUM HEATING PUMP TO DRYING CYLINDER

existing in the condenser. Loss of volumetric efficiency through re-evaporation of water in the clearance space is consequently eliminated and the vacuum produced corresponds closely to the temperature of the water present in the pump. The heat generated by compressing the air is absorbed by the water carried around with the rotor and makes the compression closely follow the ideal or isothermal curve.



PHANTOM VIEW OF ROTREX VACUUM PUMP IN PART SECTION

The cast-iron cylindrical rotor is internally balanced, permitting operation at speeds from 200 to 500 r.p.m. and without appreciable vibration.

Rotrex pumps operate either on the wet or dry vacuum system. When running dry, a small amount of cooling water is admitted into the air intake and carried through the pump to the discharge chamber above the valves, where it collects, filling the space above the valves and forming a water seal for the latter. The surplus water which is carried out with the air can be used as makeup for the boiler feed.

Centrifugal Pumps

TAKING advantage of the centrifugal force of a mass of water traveling in a circular path, the centrifugal pump has been devised to raise liquids against almost any commercial pressure. This pump consists essentially of an impeller, which gives motion to the water, rotating inside a casing which guides the water to the center of the impeller and conducts it away from the periphery, thus preventing its return to the suction side.

Water coming to the center of the impeller is caught by the blades, or vanes, as they are called, of the impeller, and given a rotating motion, thus taking energy from the impeller and converting it into centrifugal force in the water. This force drives the water at high velocity to the periphery of the impeller, where the velocity energy is converted into pressure energy by reducing the speed; the method employed is by increasing the area of the path of the water from the impeller to the discharge from the pump. This energy conversion may take place across the flowing stream of water in any or all of the 3 forms known as potential energy, pressure energy or kinetic energy.

Centrifugal pumps are not of the positive displacement type, which distinguishes them from those having pistons and the class known as rotaries, and this characterization adapts them for use in many places where the displacement pump is impracticable.

Classification into Types

According to the method of converting the energy from velocity to pressure, centrifugal pumps may be separated into 3 types known respectively as whirlpool, volute and turbine.

In the whirlpool type, the form of the casing is such that a ring of water, the same width as the openings in the impeller, surrounds the impeller. In this chamber, the water leaving the impeller has a tangential component and the path of the water takes the form of a spiral; as the area increases, the water diminishes in velocity and increases in pressure as it approaches the outer circumference of the chamber. Surrounding the whirlpool is a spiral or circular chamber which conducts the water to the discharge pipe.

Volute pumps differ from the whirlpool type in that no whirlpool chamber is provided, the energy transformation taking place in the spiral, or more properly speaking, volute casing. The design of the casing is such that the velocity of flow is equal at all sections around the circumference and the velocity of the water is gradually reduced from the impeller to the discharge, and this is accompanied by an increase in pressure.

By directing the water discharged from the impeller in more nearly its natural course, a gain in efficiency is obtained over the whirlpool type, owing to reduced friction. A gain in capacity is also secured by this construction, as leakage past the impeller is cut down.

Turbine pumps differ from whirlpool types only in the provision of diffusion vanes in the whirlpool chamber. These vanes direct the water in gradually widening paths, which have been found to convert the velocity energy to pressure most efficiently.

Types of Impellers

Centrifugal pumps differ greatly in the design of the impellers employed, which is determined largely by the class of service to which the pump is to be put and to some extent by the designer's ideas.

Starting originally with straight radial vanes, these were modified to the inclined position, but practically all modern centrifugal pumps have impellers designed with vanes of circular shape with involute tips; in some cases, however, this form is modified, combining it with that of a spiral propeller, which makes an impeller particularly adapted to low heads and large volumes at high speeds of the shaft.

Impellers may be either open or closed, the open type having vanes that run close to the sides of the casing, this clearance being depended upon to prevent leakage from discharge back to suction, and owing to friction of a close running fit, this type is not suited to high heads.

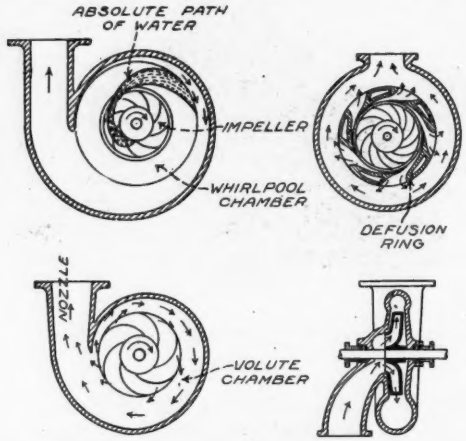
Closed impellers have vanes properly spaced between 2 disk-like faces, these being attached to the hub and keyed to the shaft. Leakage back to suction is prevented by close fitting rings either at the hub or the circumference of the impeller. These rings take the form of labyrinth packing in some pumps working against high heads; the high friction resistance through these rings reduces leakage to a minimum.

Impellers may also be classified into single suction and double suction, according to whether they take water from one or both sides. With single-suction impellers, considerable end thrust is encountered, particularly when the suction head is high. This difficulty has been effectively overcome by the use of double-suction impellers taking water from both sides, slight variations in the construction of the suction passages, however, are almost unavoidable and result in some end thrust, which is nearly always taken care of by thrust bearings or equivalent devices.

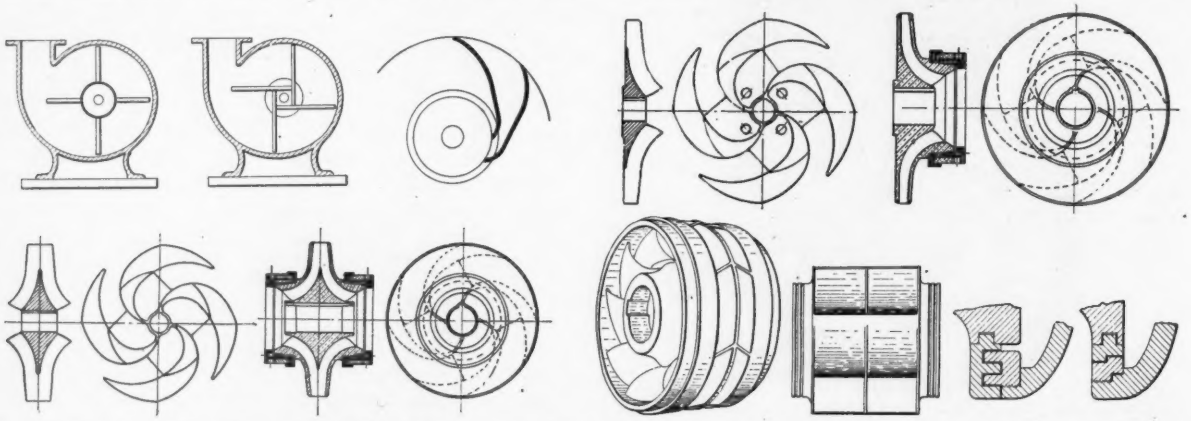
Horizontal and Vertical Pumps

Another classification of centrifugal pumps is based on the position of the shaft; those having horizontal shafts are called horizontal pumps, and those with vertical shafts, vertical. Wherever conditions will permit, the horizontal pump is preferred, as end thrust is unavoidable in vertical pumps, and a special bearing is a necessity.

The principle of operation of the horizontal and vertical pumps is identical, but in order to adapt the pumps to locations where they work most efficiently, the form of the casings are entirely different, as will be noted in the commercial descriptions which follow. The form of impeller used depends in all cases upon the class of service to be performed, but a common arrangement for vertical pumps is a single suction impeller with the suction connection above the casing; this overcomes to some extent the thrust of the shaft and is particularly desirable where the suction head is high.



WHIRLPOOL TYPE CENTRIFUGAL PUMP
TURBINE TYPE PUMP
PUMP WITH VOLUTE CASING



TYPES OF IMPELLERS AND PACKING RINGS: STRAIGHT RADIAL; INCLINED RADIAL; CIRCULAR ARC WITH INVOLUTE TIPS; "AMERICAN" SINGLE-SUCTION OPEN, SINGLE-SUCTION CLOSED, DOUBLE-SUCTION OPEN, DOUBLE-SUCTION CLOSED; DOUBLE CURVED; LARGE CAPACITY DOUBLE IMPELLER; VERTICAL AND HORIZONTAL LABYRINTH PACKING

Staging

So far, pumps with only one impeller have been considered. These have their limitations as to the head against which they will operate, depending upon speed and design, so, by arranging 2 or more impellers on one shaft, the discharge of the first impeller being to the suction of the second, and so on to the third, fourth, etc., the pressure is built up in each impeller, giving a total pressure 2, 3 or 4 times, depending upon the number of

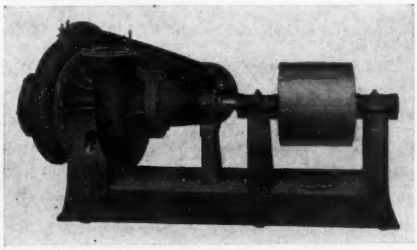
impellers, what is obtained from one impeller. The difficulties encountered in staging impellers are principally in overcoming increased end thrust, complicated casing construction and leaking stuffing boxes.

In the 2-stage design of the Keystone Driller Co.'s Downie centrifugal pumps, the runners are placed back to back, the discharge from one connecting to the suction of the other, the runners being placed in separate casings which are detachable. These pumps are adaptable to any form of drive, and for 2-stage pumps the arrangement is well adapted.

A similar arrangement is used in staging vertical centrifugal pumps made by the Advance Pump & Compressor Co., as shown in the illustration, the impellers being placed in separate casings with their suctions at opposite sides, the discharge from the first stage being led by a cross-over to the suction of the second. The 2 volutes are held together by a cast-iron yoke which is supplied with a removable bronze bushing. This bushing acts as a guide bearing for carrying the runner shaft.

Effects of Speed

In the performance of a centrifugal pump, there is a direct relation existing between the speed and head, and speed and capacity, which is most clearly understood by referring to curves plotted from the results of



KEYSTONE DRILLER CO.'S DOWNIE 2-STAGE PUMP

tests of commercial pumps. The accompanying curves are plotted from the results of tests on a 4-in. pump, and while their shape may vary considerably with the type of impeller, they are characteristic of centrifugal pumps in general and will serve to give an idea of the relations existing.

From the speed-head curve, it will be noted that the head is almost directly proportional to the speed, with a tendency towards more rapid increase in head as the speed advances, the discharge remaining constant.

From the speed-capacity curves we note that, with constant head, at the lower outputs speed changes are accompanied by great changes in output, but as the speed and capacity increase, changes in speed are not accompanied by so great changes in capacity. For example, if the head is maintained constant, a slight flow through the pump will be accompanied by a decrease in speed from the no capacity condition; this relation soon changes as the capacity increases when the curve indicates increase in capacity is secured by increase in speed.

Another interesting relation which is of importance in designing impellers is that of the area of the impeller to the capacity. As might be expected, the capacity will increase in direct ratio with increase in area of the impeller, the relation being expressed in a formula given by Daugherty as follows:

$$f_2 = \frac{\text{G. P. M.}}{448 \times c\sqrt{2gh}}$$

In which f_2 = area of stream normal to the direction of flow in the impeller passage at the exit, G. P. M. = discharge in gallons per minute, c = a constant varying from 0.1 to 0.3, g = acceleration due to gravity = 32.16, and h = head, in feet, developed by the pump.

Pump Characteristics

In the operation of centrifugal pumps, the characteristics of the pump as plotted from tests should be carefully studied, for in this way only can the best results be obtained. In selecting a pump for a given service, it is well, however, to consider a few fundamentals which govern the efficiency to a great extent. Sometimes the method of driving may be varied to ac-

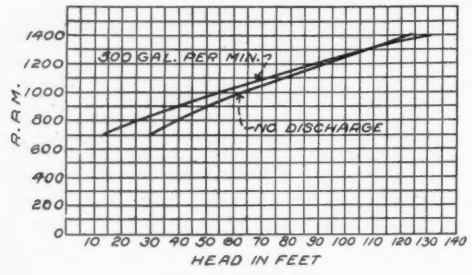
ADVANCE VERTICAL 2-STAGE PUMP

commodate the most efficient type of pump, in other cases variations in head are encountered, or, as met in boiler feeding, variations in capacity are necessary. Other conditions might be cited, but these are sufficient to convey the idea that an impeller designed for one service is not necessarily efficient in another.

By type of impeller is meant here the ratio of diameter to width. It is evident that by variations in speed, the same head can be obtained by impellers of different diameters, and in order to secure the same capacity with variations in diameter, the width must be varied. Taking into effect the losses due to mechanical and hydraulic friction, tests have shown that pumps with low ratios of diameter to width have the higher efficiencies.

Centrifugal pump efficiencies are affected by changes in capacity, head or speed, the curves varying somewhat with the type of pump. The accompanying curves show these relations taken from tests of a large number of pumps.

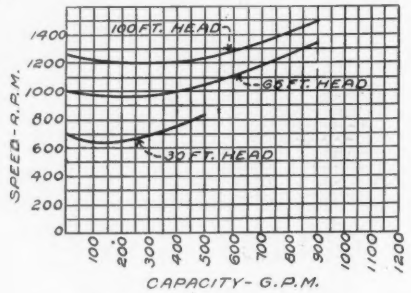
While high efficiency in operation is always desirable, it is sometimes necessary to sacrifice for other considerations. For example, in dredging, large areas must be provided in order to allow trash to pass, and such construction cannot give the highest efficiency. Sizes also affect the efficiency, for in the smaller sizes, losses due



SPEED-HEAD CURVES

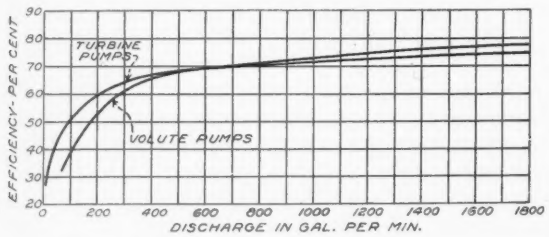
to friction are proportionately higher. In small pumps, efficiency varies from 30 to 40 per cent, while in large sizes, 75 and even 85 per cent have been attained.

In the illustration are given the characteristics of an 8-in. pump of the single stage type designed for constant high speed and a head that does not vary greatly but will allow of some fluctuation and still maintain high efficiency.



SPEED-CAPACITY CURVES

In another set of curves are given the characteristic of a pump designed for dry dock service, where the head varies greatly but the speed is maintained constant. Here it will be noted the head starts to decrease the instant flow begins and continues at a gradually increasing rate down to a maximum discharge at no head. At the same time, the efficiency rises rather abruptly, becoming more gradual as the highest point is ap-



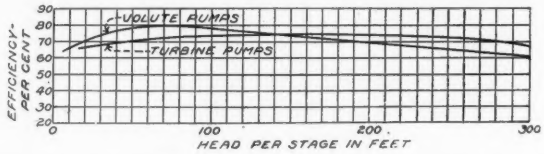
EFFICIENCY-CAPACITY CURVES

proached, where it remains quite constant during considerable decrease in head, then descends abruptly.

While to secure highest economy centrifugal pumps must be built for specific conditions of capacity, head and speed, it is still possible to vary operating conditions and obtain a fairly high efficiency, as will be seen from the set of curves showing the effects of variation in speed upon head, efficiency and capacity.

Reasons for Staging

Single stage pumps designed for the same capacity with the same diameter of impellers, but varying widths, and for different speeds, vary in efficiency as the operating head is changed. Thus for a volute pump, highest efficiency is obtained when the head is between 60 and 80 ft., for turbine pumps the high efficiency point is between 140 and 170 ft. head. To operate at much

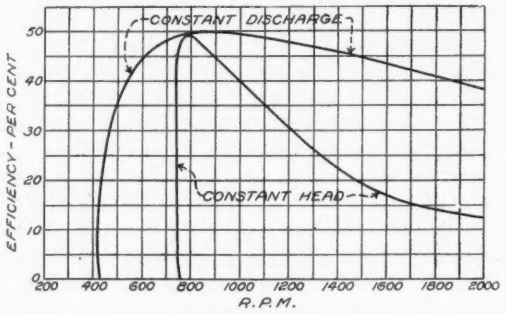


EFFICIENCY-HEAD CURVES

higher heads than these, best results can be obtained by staging the impellers, that is, putting them in series. By this arrangement, leakage losses are reduced, the head per stage may be chosen for highest efficiency and the pressures obtainable are not limited to one impeller but may reach considerably above a thousand pounds.

Installation of Centrifugal Pumps

Successful operation of a centrifugal pump is influenced quite largely by the condition under which it is installed. The first consideration is the foundation, which should be rigid, as a vibrating pump is sure to set up unnecessary friction and leakage losses. The pump should be placed as near the level of the water to be pumped as possible, for a suction head is not taken care of so efficiently as a discharge head. It is pos-



EFFICIENCY-SPEED CURVES

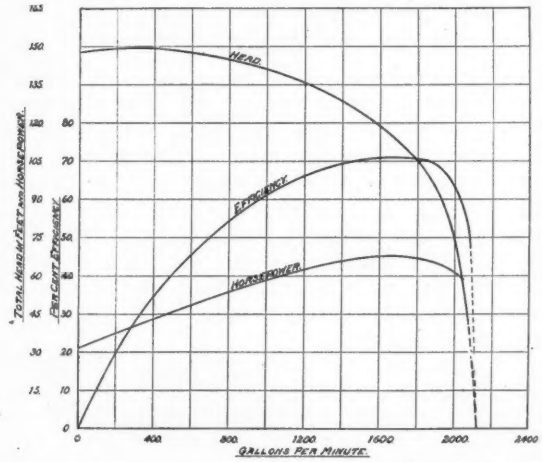
sible, however, to operate with good results with a suction head of 25 ft. when conditions require such an installation.

When placed above suction water level, some provision must be made for priming centrifugal pumps, for the pump casing and suction pipe must be completely full of water or it will not start. When used to handle hot water, they must always be placed so that the water will flow into the pump.

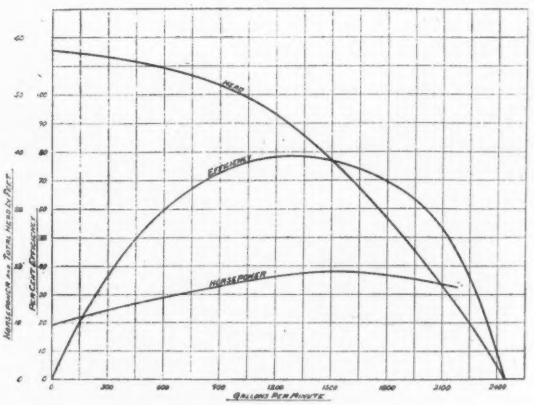
For priming centrifugal pumps, a hand operated device, such as shown attached to the Barnes' pump, is simple and effective, consisting of a small air pump attached to the suction-connection of the pump, and re-

quires no other fitting than a tight valve on the discharge side, but is rather slow and laborious on large pumps, so other means are frequently provided.

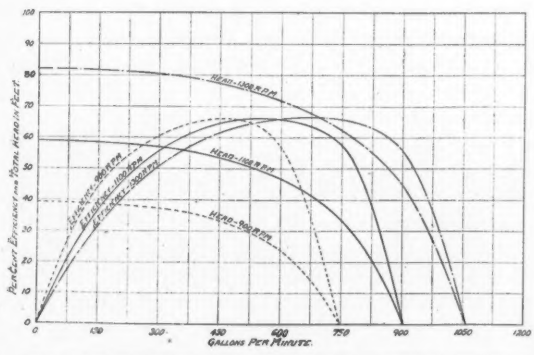
Priming by means of an injector is a favorite method. The ejector is attached to the top of the pump casing, and with a flap valve in the discharge line, the air is



CHARACTERISTICS OF A HIGH-SPEED 8-IN. PUMP



CHARACTERISTICS OF A PUMP FOR VARIABLE HEAD AND CONSTANT SPEED



CHARACTERISTICS OF A PUMP RUN UNDER VARYING CONDITIONS

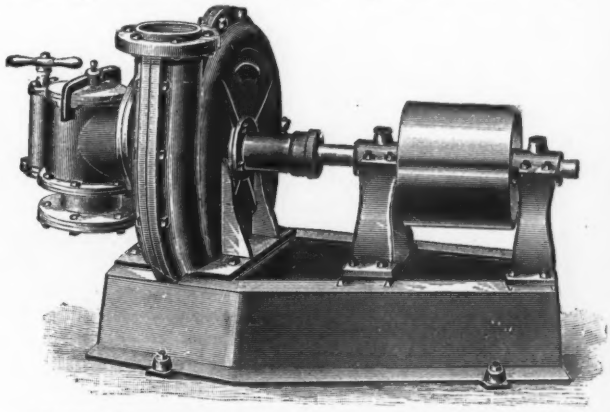
exhausted from the pump and the water rises to fill the space. In long discharge pipes, a flap valve of the ordinary type cannot be used in connection with a steam ejector; under these conditions, the suction pipe is fitted with a foot valve and the ejector draws the water through a separate pipe and delivers it to the pump.

Where water from a tank or other source is available, this may be used to fill the casing by placing a foot valve on the end of the suction pipe. Once a pump provided with a foot valve is started, it will not need priming after periods of idleness, unless the water is let out of the suction pipe.

Piping in all cases should be as direct as possible, and the bends should not be abrupt but rather sweeping, in order to cut down friction, and it is frequently advisable to increase the size of the piping from the pump by taper connections in both suction and discharge piping.

Uses for Centrifugal Pumps

Centrifugal pumps are being used more extensively now than ever before for feeding boilers, and while the high head and small delivery, which are necessary characteristics, are not conducive to highest economy, when driven by steam turbines, the exhaust is used for heating feed water and little loss is encountered. For this class of work, the pump should give a decreased rate of discharge with increase in head pressure due to the



BARNES' CENTRIFUGAL PUMP WITH HAND PRIMER

partial closing of feed water regulators, and vice versa. The success of centrifugal pumps in this field is due to the ease with which the discharge can be controlled, and the absence of shocks and pulsations in the delivery pipes.

The Economy turbo-pump, made by the Kerr Turbine Co., is a compact unit designed for boiler feeding purposes, and possesses all the requirements for successful operation as stated above. The general appearance is shown in the illustration.

For fire protection, centrifugal pumps are well adapted, for they are reliable and usually less expensive than other types, points which outweigh others for this service. Pumps for this service should have flat characteristics.

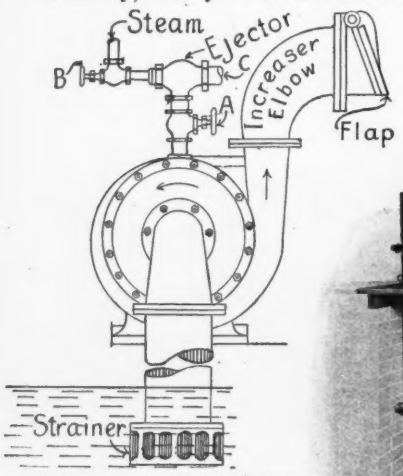
Vertical pumps have their field in deep wells, mine sinking, sewage ejection, etc., where it is difficult to attach the driving element close to the pump.

A sump pump built by Wm. E. Quimby, and illustrated here, is an example of this vertical shaft type. The bearing which guides the impeller and vertical shaft is situated at the level of the sump pit cover instead of being at the pump, thus keeping it out of gritty water. The pump is suspended from the cover plate by a steel tube through which the vertical shaft passes. The discharge pipe passes through the cover plate from which

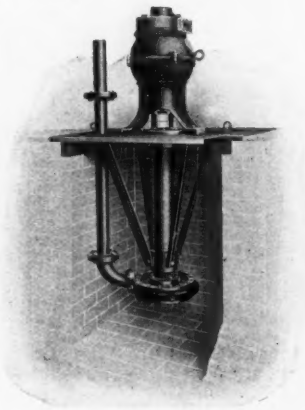
the pump is suspended, and is rigidly fastened to the plate. The suspension pipe and discharge pipe hold the pump rigid for suspension of not more than 4 ft., diagonal braces are used to obtain the rigidity which is necessary to quiet and successful operation. The suction is at the bottom of the pump, and the pump is usually set so that the bottom of the pump is 4 to 6 in. above the bottom of the pit.

Another type of vertical centrifugal pump is made by The Deming Co., either for submerged use or for suction work. The suction type shown here is used largely in draining coffer dams, sewers and various kinds of excavations, where the supply is either below the pump, or sometimes above, as it will also run submerged. The difference between the submerged and suction pumps is that the suction type is provided with a yoke which supports the entire weight of the shaft and also with a gland which is provided with a water seal.

In dredging work, centrifugal pumps are used exclusively, as they are able to handle large pieces of solids



METHOD OF CONNECTING EJECTOR FOR PRIMING EMPLOYED BY AMERICAN WELL WORKS



QUIMBY SUMP PUMP

without injury. They are subject to rapid wear in this work, owing to the erosive effect of sand and gravel, and in some cases are lined with steel to resist wear.

For general service about a power plant, centrifugal pumps have met with good success. In such cases, they are usually motor driven and are designed to operate against varying heads. They have the advantages of being less expensive and smaller for their capacity than other types, and are quiet in operation.

Such a pump is made by the Hill Pump Co., and the illustration shows it to be of the single-stage double-suction type with a volute case split horizontally in a plane with the shaft. The shaft bearings are bolted securely to the lower half of the case, making the bearings entirely independent of the stuffing boxes, which prevents the in-leakage of air around the shaft of the pump. These pumps are mounted upon a single base with a driving motor to which they are connected by means of a flexible coupling.

Circulating water for condensers is a service to which centrifugal pumps have been put in recent years, one of the favorite arrangements being a geared connection to a steam turbine as illustrated in the view of the Economy geared single-stage turbo-pump made by the Kerr Turbine Co. The comparatively low head and the large volume required for this service have made an efficient direct connected turbine unit without gearing an exceedingly special problem.

Operation

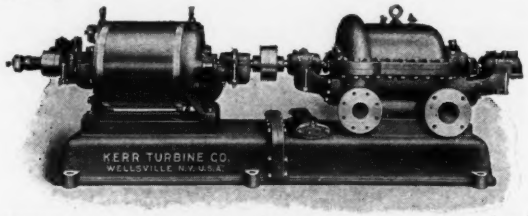
Before starting a centrifugal pump, the discharge valve should be closed. This is not only necessary in order to prime the pump with some arrangements, but prevents an excessive starting load. After the pump is primed, it is brought up to speed with the discharge valve closed, then the valve is slowly opened to the point where sufficient discharge is obtained. Further attention required is merely to see that bearings are operating properly, that water is circulating in the thrust bearing when this type of bearing is used and that the stuffing boxes do not leak.

To shut down the pump, first close the discharge valve slowly, thus reducing the load on the driving motor before it is stopped and preventing any surge in the pipe line.

The cost of pumping water may be calculated by the accompanying charts, published by Henry R. Worthington, when the installation conditions are known and efficiency of the unit determined.

Testing Centrifugal Pumps

After a pump has been installed, it should be tested, first, to see that it comes up to specifications, then occasional tests to see that the pump is maintaining its efficiency.



ECONOMY TURBO-PUMP DESIGNED FOR BOILER FEEDING

In making an acceptance test, the pump should be run under varying conditions so that the characteristics may be plotted in curves. In making these tests, one of the 3 variables, speed, head or discharge, should remain constant, while the others vary throughout the range of the pump; by this procedure, the 3 characteristic curves can be drawn.

To measure the head, a calibrated gage may be used on the discharge as close to the pump connection as convenient, and on the suction side, a mercury gage serves well when the water is to be lifted, but when it comes to the pump under pressure, a pressure gage may be used, although a mercury manometer is more accurate. The gage connections should be flush with the inside surface of the water pipes for accurate results. And in calculating the head allowance must be made for the difference in level between the vacuum gage and the center of the pressure gage.

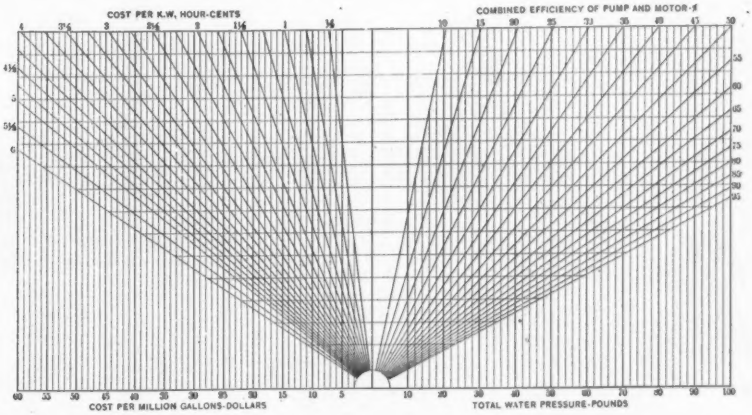
To determine the amount of discharge, the method employed will depend upon the means at hand. It may be weighed by water scales or measured with a weir, a

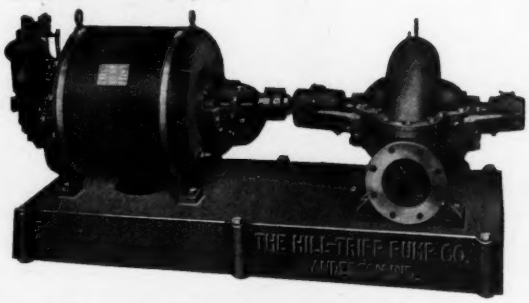
Venturi meter, a Pitot tube or any form of reliable water meter. Time enters into this measurement and the amount of discharge over a given period should be kept accurately. Extending the test over a longer period of time will tend to give better average results in this test.

Speed may be taken with speed indicator and stop watch, but a calibrated tachometer will give better results.

DEMING SUCTION TYPE VERTICAL PUMP

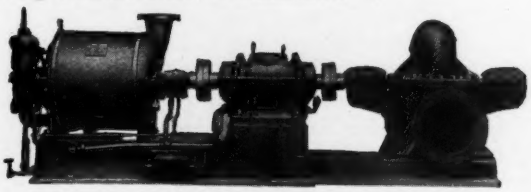
COST OF PUMPING 1,000,000 GAL. WATER BY ELECTRIC POWER


COST PER K.W. HOUR-CENTS
COMBINED EFFICIENCY OF PUMP AND MOTOR-%
COST PER MILLION GALLONS-DOLLARS
TOTAL WATER PRESSURE-POUNDS



HILL GENERAL SERVICE PUMPING UNIT

To determine the power consumed with a motor driven pump, the wattmeter is most satisfactory. This reading should, of course, be reduced by the amount of power lost in the motor. For engine driven pumps, the indicator serves well and for turbine drives, a steam meter may be used, in each case the efficiency of the driving element must be considered.



ECONOMY GEARED SINGLE-STAGE TURBO-PUMP

American Centrifugal Pumps

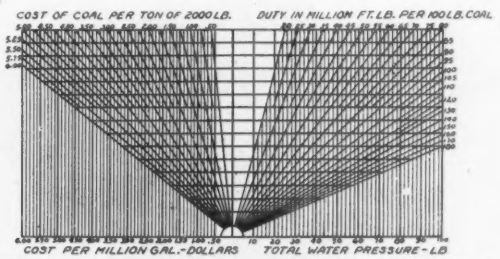
In centrifugal pumps of the single-suction type, made by The American Well Works, the cover is cast in one piece with the supporting pedestal. In the double-suction type the shell is made in 2 pieces split in the horizontal plane with both suction and discharge connection on the lower half.

Labyrinth packing rings are used on all enclosed types of impellers. Back to back arrangement of 2 single-stage single-suction pumps is sometimes used for a 2-stage pump.

Besides the ejector method of priming this company employs an automatic device, shown here in cross section, which is used where the suction pipe layout is such that the pump may lose its priming. When the discharge pipe has once been filled this device keeps the pump primed, provided water always remains in the discharge pipe. This is accomplished when discharge is into a stand pipe tank or other elevated receptacle by placing a check valve in the discharge pipe and a foot valve in the suction pipe, and carrying water by the check valve with the automatic device to the suction side of the pump. The cut also shows an automatic air extracting chamber, which removes air from the pump casing. These devices are of particular advantage when remote control of the pump is desired.

The "American" deep well turbine centrifugal operating in combination with a vertical type centrifugal on the same shaft represents the development of the centrifugal principle of pumping in water-works installations where it is desired to pump water from deep wells and produce a pressure in the mains with a single pumping unit.

COST OF PUMPING 1,000,000 GAL. WATER BY STEAM POWER

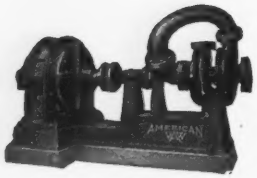


This pump consists of a turbine centrifugal at the pumping level in the well and a vertical type centrifugal at or near the surface, operating on the same shaft and propelled by a single vertical type motor.

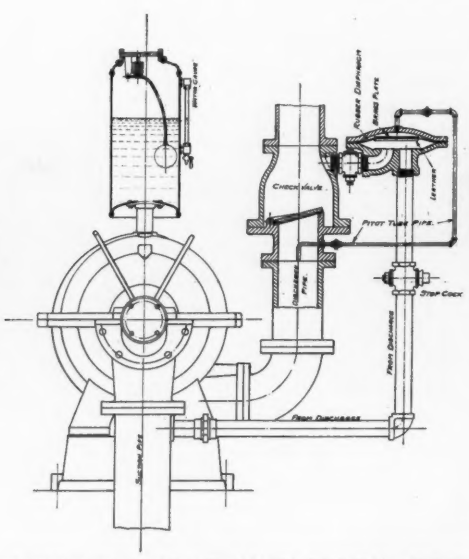
The turbine raises water to the surface and delivers it to the vertical type centrifugal, which produces the required pressure in the mains. Any number of stages the conditions require may be used, both in the tur-

bine pump in the well and the vertical centrifugal at the surface.

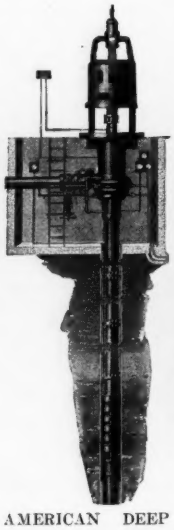
In this installation the weight of the shaft and attached impellers is carried partly by a hydraulic balancing device and partly by a large roller disk thrust bearing at the surface. The motor is attached by flexible shaft coupling. All lubricating is done from the surface.



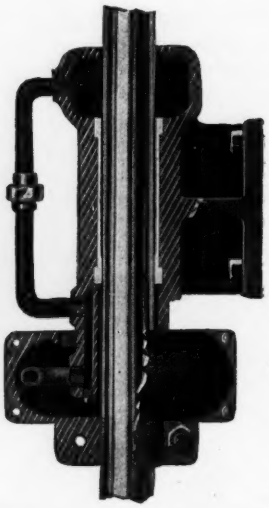
AMERICAN BACK-TO-BACK 2-STAGE PUMP



SECTIONL VIEW OF AUTOMATIC PRIMING DEVICE



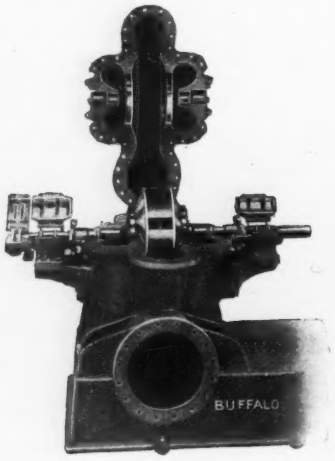
AMERICAN DEEP WELL TURBINE PUMP



SHAFT GUIDE FOR BUFFALO VERTICAL PUMP

Buffalo Centrifugal Pumps

Buffalo Steam Pump Co.'s centrifugal pumps are made in a large variety of types to suit all conditions arising where liquids are handled; among them are single and multi-stage, single and double suction, single-stage, horizontal and vertical.



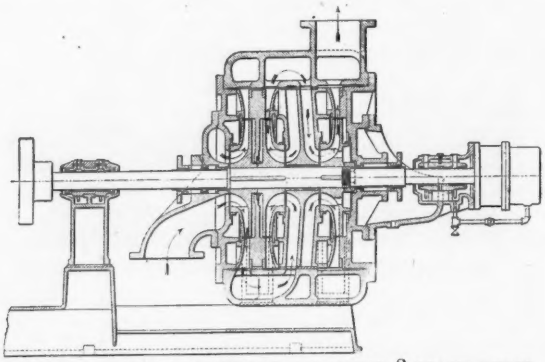
LARGE DOUBLE SUCTION PUMP WITH COVER RAISED

Single-stage pumps designed for the highest class and most exacting service have the shell cast in 2 pieces, split in a horizontal plane through the shaft with suction and discharge connections on the bottom half.

The impeller to be used varies with the service to which it will be put. The regular impeller used on standard single suction pumps is a one-piece solid casting of the enclosed type with balancing chamber opposite the inlet opening. In the double-suction pump the impeller is also of the enclosed, one-piece type. In small pumps a 2-piece single suction type runner is sometimes employed. It is made of brass with vanes cast on one side; the other half of the runner is a plain circular casting which is riveted to the side carrying the vanes, thus forming passage-ways that are accurate in curvature.

For very large double suction pumps, a dividing web extends from the hub clear to the periphery of the impeller, which is of the enclosed type, thus giving strength to the vanes. For low heads and water containing foreign solids an open type impeller is employed.

Buffalo multistage pumps are also built in the turbine type with diffusion vanes. The shell in all cases is cast in one solid piece; the design is girder-like in strength, being of box construction. Ribbed side plates are fitted within each end of the shell, the suction side plate carrying the suction inlet elbow and so arranged that neither need be removed from the pump when taking it apart. The discharge side plate carries the



SECTIONAL VIEW OF BUFFALO BALANCED 3-STAGE PUMP

bracket supporting the outboard bearing and has bolted to it the interior stationary parts of the pump.

In staging these pumps, the impellers are opposed, that is, placed back to back in pairs. This is accomplished by the use of diaphragms and return chambers. The diaphragm is provided with a wide, floating bronze clearance ring to prevent leakage between stages. The return chamber contains passages carrying water from the discharge of one impeller to the suction of the next.

Within the pump and through the glands all shafts are protected by removable bronze sleeves. The suction gland is provided with water seal to prevent entrance of air. Shaft bearings are of the ring oiling type. Although these pumps are hydraulically balanced, to provide against exceptional conditions a thrust bearing is provided.

A prominent feature of Buffalo vertical shaft centrifugal pumps is the method of keeping the guide or steady bearing automatically lubricated. The illustration shows clearly the construction of the bearing with a whirling oil chamber at the bottom. The whirling oil is caught in the mouth of a short oil tube which conducts it to the upper part of the bearing.

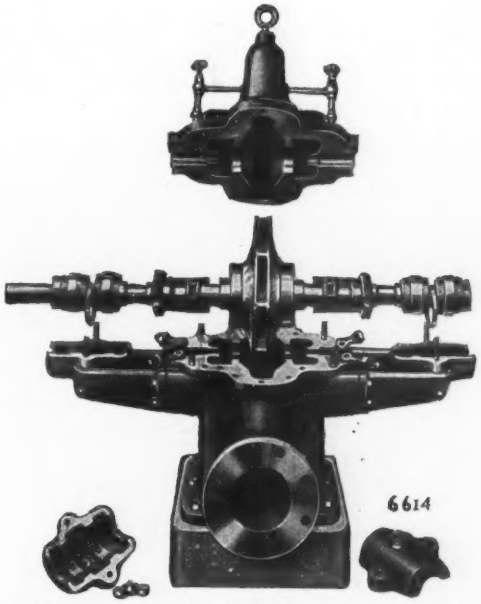
Cameron Centrifugal Pumps

The Cameron double suction volute pump is designed for use where the head does not exceed 200 ft., although higher heads may be placed upon the pump, depending upon the capacity desired and speed avail-

CAMERON SINGLE-SUCTION OPEN IMPELLER PUMP, ARRANGED FOR FRAME WORK OF WOOD OR IRON

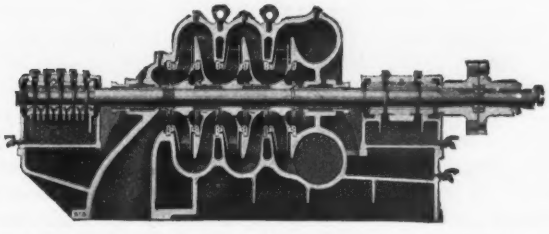
able. This pump is designed for direct connection to motor, turbine, gas engine, or may be belted to suit conditions. The pump casing is horizontally split and cast integral with side heads and stuffing boxes. The impeller is of the enclosed type and designed to reduce the losses due to shock and friction to a minimum, that is, the entrance and exit angles of the impeller vanes and its curvatures are developed to accomplish that result. There are double wearing rings fitted around the inlets of the impeller, one being stationary and attached to the casing, and the other attached to and revolving with the impeller. The design of these rings gives broad and accurate bearing surface, reducing leakage from the discharge to the suction chamber to the minimum.

The shaft is made of steel, and provided with renewable bronze sleeves to protect the shaft from corrosion and take up all wear in the stuffing boxes. The sleeves are screwed onto the shaft and hold the impeller in a central position.



CAMERON DOUBLE-SUCTION VOLUTE PUMP, CASING OPEN

Cameron centrifugal pumps are also made in vertical type, the general construction of which is similar to that already described, except in regard to bearings. In the case, however, of the single suction vertical type the casing is split at right angles to the shaft and the impeller is of the open type. In this case the thrust bearing is entirely external to the pump, and is supported on an independent bracket, enabling it to be located either at the pump or overhead in case the pump is to be operated submerged. The thrust bearing con-



TYPICAL SECTION OF A DE LAVAL MULTI-STAGE CENTRIFUGAL PUMP

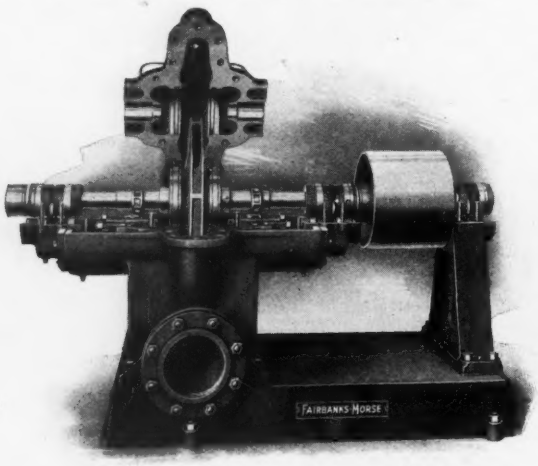
sists of a heavy cast-iron bracket containing an adjustable sleeve, so that lost motion and wear can be taken up and in this sleeve is mounted a hearth steel ball race in 2 parts, with large diameter steel balls. Surrounding the race and the balls is a chamber arranged to be flooded with oil so that perfect lubrication is obtained at all times.

De Laval Centrifugal Pump

The enclosed or shrouded impeller is used in all centrifugal pumps made by the De Laval Steam Turbine Co. The entering and leaving angles of the impeller vanes, and the cross section of the passages vary according to the service to which the pump is to operate. The impellers are finished on all surfaces, the vanes being filed and polished to templets that have the theoretical curvature.

Bearings are held in pedestals or brackets which are entirely separate from the pump casing and stuffing boxes, eliminating the possibility of water finding its way into the bearings and oil reservoir.

Water joints are located at the points where the shaft penetrates the casing, also the clearances between the impeller and the casing. In the single-stage pumps both of the external joints are ordinarily not subjected to pressure, but to suction, and the principal thing to be guarded against is the in-leakage of air. For preventing this, a hollow skeleton ring is placed in the middle of the packing so that water under pressure can be admitted to form an air-tight seal, preventing the entrance of air.



FAIRBANKS-MORSE SINGLE-STAGE, DOUBLE-SUCTION, CENTRIFUGAL PUMP

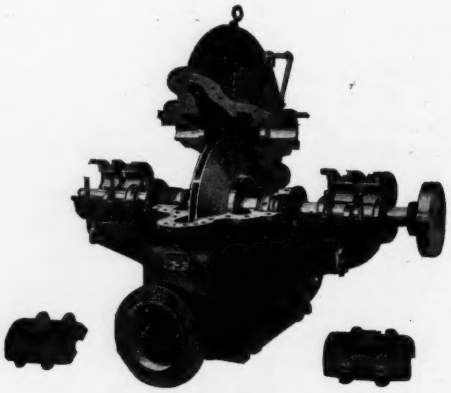
One of the principal features of the De Laval multi-stage centrifugal pump is that the individual housings are merged into a common housing, and for the volute on the single-stage pumps is substituted an annular discharge chamber from all points on the circumference of which water flows directly to the suction inlet of the succeeding stage. These pumps are also parted on the horizontal plane passing through the center of the shaft, making the interior of the pump accessible for inspection or repair. The passages from the discharge of one stage to the suction of the next stage are formed within the casing.

The method of balancing employed in these pumps consists of producing the same pressure conditions on both sides of each impeller by using 2 sets of labyrinth wearing rings of the same diameter, one set on each side of every impeller. The labyrinth rings on the back of the impeller enclose the balancing chamber which has the same cross-sectional area as the suction chamber, being enclosed by labyrinth rings of the same diameter as those encircling the suction opening. The chamber is limited on one side by the diaphragm of the pump casing, and on the other by the web of the impeller, which is pierced by a number of holes connecting the balancing chamber with the suction chamber. These holes insure that the side pressure existing in the suction chamber shall be transmitted to the balancing chamber, also that an exact pressure shall be generated in the balancing chamber approximately equal to the thrust, due to the action of the column of water entering the suction of the impeller. The impeller itself is of the enclosed single-suction type.

Fairbanks-Morse Centrifugal Pumps

In the single-stage type of Fairbanks-Morse & Co.'s centrifugal pumps, both double and single-suction impellers are employed.

The impeller is of the inclosed type, with the angles of the vanes designed to produce the best results, at the same time protect the driving motor against serious overload if for any reason the head is suddenly reduced. The double-suction type of pump has the casing divided



OPEN VIEW OF GOULDS SINGLE-STAGE, DOUBLE-SUCTION PUMP

on the horizontal center line, the bottom half carrying the suction and discharge connections, also the bearing brackets which support the outboard bearings.

In the heavy duty, single-suction type the volute is provided with feet for mounting on the base, and side plates are bolted to both sides. The heavy duty, side-suction pump is provided with outboard bearings and water-sealed glands.

Goulds Centrifugal Pump

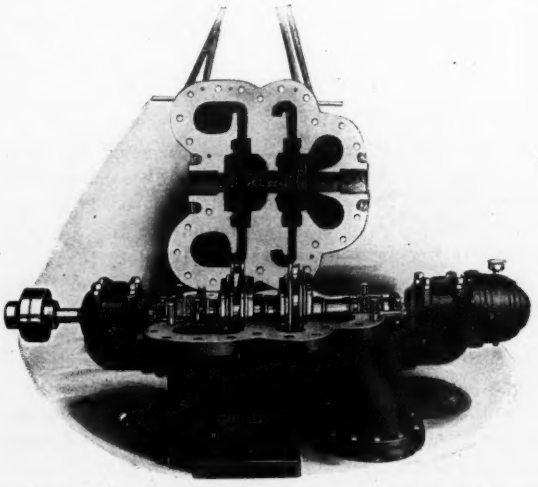
Two general types of single-stage centrifugal pumps are manufactured by The Goulds Manufacturing Co., these being the double-suction and the single-suction type. The impellers of the double-suction type are so arranged that water is drawn in at both sides at the center with the 2 streams directly opposite.

Owing to the double-suction feature of the impeller, the pump is hydraulically balanced against end thrust so that no thrust bearing is provided, but to limit the lateral motion of the impeller, collars are placed on the shaft close to the removable bearing shells.

The single-stage, single-suction centrifugal pump made by this company differs somewhat in construction, being designed for more general service with the volute case in one piece to which a head is bolted. The impeller is of the open type, which allows the pump to handle muddy, sandy or gritty water.

While the impeller of these pumps is designed to minimize the end thrust which must occur in all single-suction centrifugal pumps, a thrust collar fastened to the shaft and bearing against a babbited surface is provided as a safeguard.

For pumping against 100 to 300 lb. Goulds centrifugal pumps are made up into 2 or 6 stages with capacities ranging from 20 to 1500 g.p.m. This type of pump is designed particularly for fire protection service, for which it is admirably adapted. The casing consists of



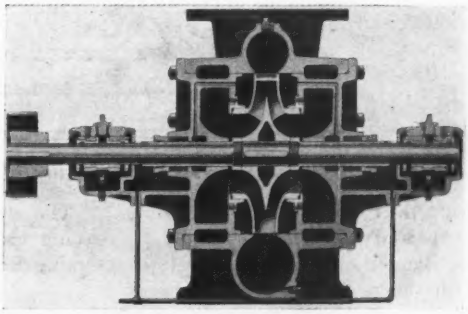
GOULDS 2-STAGE PUMP WITH TOP HALF OF CASING RAISED

2 castings and is horizontally divided on a plane passing through the center of the shaft. Both suction and discharge nozzles are cast integral with the lower half. The upper and lower half of the castings are bolted together and maintained in strict alinement by means of tapered dowel pins. By removing the upper half the impeller and shaft, as well as the water passages of the pump, are exposed, which permit the pump to be inspected or dismantled without breaking either the discharge or suction pipe connection.

Kingsford Centrifugal Pumps

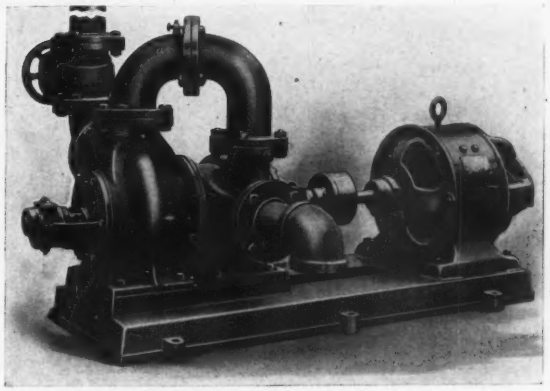
In the illustration is shown a cross section of the single-stage, double-flow centrifugal pump which embodies many features peculiar to the entire line of pumps made by Kingsford Foundry & Machine Works. The impellers are single castings integral with the balance rings and are made of bronze. In the standard designs the vanes are so shaped that a sudden drop in the discharge head will not overload the prime mover beyond 10 or 15 per cent. Leakage from the pressure to the suction side of the impeller is reduced to a minimum by packing rings of bronze. These are securely attached to the heads by screws and in connection with the rotating rings on the impeller form part of the automatic water balancing device which overcomes all tendency to thrust the shaft in either direction.

Another arrangement of Kingsford double-flow pumps is in the multi-impeller type which may be used to advantage for heads which are too high to be taken care of by a single-stage pump, where gritty or unclean liquids are to be handled. This construction is limited to the 2-stage type. As will be noted in the illustration, 2 standard main casings are bolted together and the water is conducted by a goose neck from the discharge of one stage to the suction of the second stage. The entire interior of the pump can be taken out without disturbing any pipe connections or without removing the pump from its sub-base, in the same manner as in the single-stage pump.



SECTIONAL VIEW OF KINGSFORD DOUBLE PUMP

Another arrangement sometimes employed, when, on account of starting conditions subdividing the total water supply into 2 or more units is not feasible, conditions arise where the fixed speed of the prime mover cannot readily be utilized to handle the desired quantity



KINGSFORD DOUBLE FLOW 2-STAGE PUMP

with a single-impeller pump at the head required. Still a direct connection with such driving element is desired, and the only satisfactory solution is found in a pump with 2 or 3 impellers connected in parallel within one housing.

Kingsford Turbine Pump

The Kingsford turbine pump is built in the horizontal and vertical styles, and is designed for belt, engine, motor or steam turbine drive. It can be made for handling any quantity of water against heads up to 500 ft., and while usually fitted with iron shell or case, steel or bronze can be used with working parts of

the same metal to suit the action of liquids which would prove destructive to iron.

The casing is annular in form and consists of suction and discharge heads, and center sections, there being a single section for each stage used. These sections are secured to the heads by bolts which pass through the solid metal of the heads and sections and are not in contact with the liquid pumped. Each section has its own feet, thus carrying its own weight. The suction inlet is placed next to the motor or driving element and the danger of high-pressure liquid coming in contact with the motor is thus avoided.

Impellers are of bronze and are of the enclosed or shrouded type, and have but a single suction. They are cast in one piece and are machined and polished both inside and outside as far as possible.

Diffusion or guide vanes receive the discharge of water from the impeller and transform it from velocity to pressure with the least possible loss from shock.

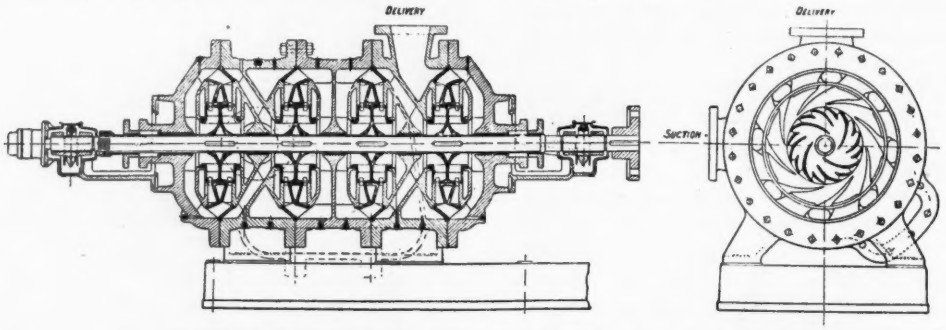
Completely covering the shaft and extending through the stuffing boxes are removable bronze protecting sleeves which in case of wear are easily replaced. The stuffing boxes are arranged for soft packing and water seals are provided on the suction and discharge sides.

Thrust is cared for by a water balancing device consisting of a piston or head secured to the shaft and working in conjunction with other parts, as will be noted by reference to the accompanying cross sectional view, in which it is shown located in the last stage on the high-pressure side of the pump.

These pumps are designed for service in water works, mines, fire protection systems and boiler feeding. They are built in any number of stages to suit pressure conditions and are usually mounted with the direct driving element upon one base.

Rees RoTURBo Pumps

The distinguishing feature of the Rees RoTURBo pump, made by the Manistee Iron Works Co., is in the construction of the impeller. This is designed in the form of a large capacity drum or pressure chamber, the object being to maintain a constant hydraulic pressure by centrifugal force inside the drum equivalent to the height of lift.



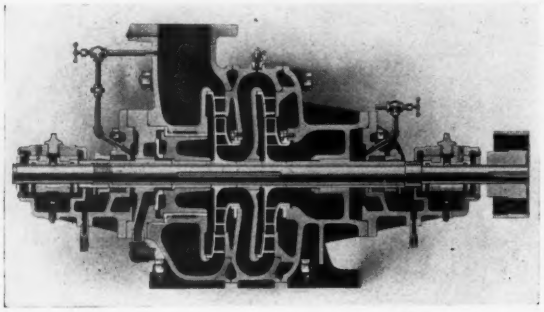
SECTIONAL ELEVATION OF REES ROTURBO MULTI-STAGE PUMPS

With a RoTURBo drum such as described, the water, after being picked up in the center or eye, moves slowly relative to the pressure drum, due to the large area, towards the periphery, thus eliminating friction losses and generating a pressure by centrifugal force.

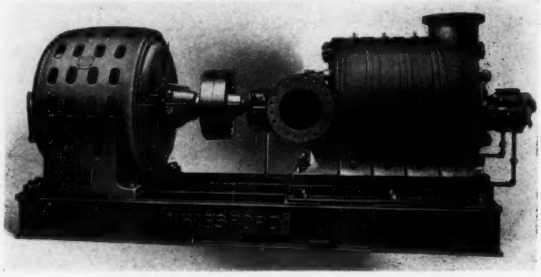
In the periphery of the drum are a series of turbine blades which point in a rearward direction, discharging the water from the drum with a strong turbine effect. This turbine effect is secured by making the drum of large capacity for storing water which is maintained by rotation at a constant internal pressure, consequently the kinetic energy is extracted from the water before it leaves the pump impeller. The result on the characteristic of the pump, due to this turbine effect, is gradually to drop the power curve as the head is lowered, enabling the pump to deliver about 180 per cent of its normal capacity at open valve with a reduced power below normal required at the duty point. This large delivery at open valve with reduced power indicates self-regulation and protection of driver without restriction of capacity by throttling at the impeller eye.

The distinguishing features of the RoTURBo pump make them efficiently adaptable for low as well as high heads.

These pumps are built up of any number of stages in such a manner that the water enters the first twin impeller, crosses in the fixture casings and enters the opposite eye of the same impeller in the reverse direction,



SECTIONAL VIEW OF 2-STAGE KINGSFORD TURBINE PUMP

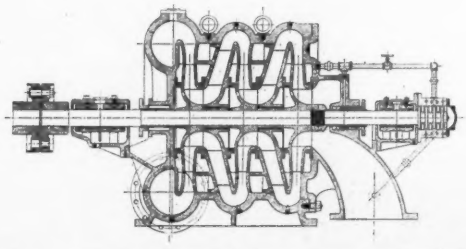


KINGSFORD 4-STAGE PUMP

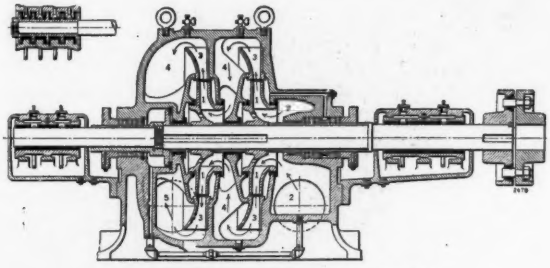
from that in which it enters the first. This flow, which may be described as a contra-flow action, goes on alternately whatever number of drums be employed, and in this way end thrust in the pump is automatically adjusted and a complete hydraulic balance obtained. Beyond the outer bearings a small centering ball race is fitted so as to maintain perfect alinement between the impeller nozzles and the fixed diffusers. The number of drums used depends upon the head against which the pump has to work, and also on the speed of the motor.

Morris Centrifugal Pumps

Where exacting service requirements must be met, and a direct-connected, high-speed driver is employed, such as turbine or motors, the casing employed by the Morris Machine Works is made in halves, split in the horizontal plane through the shaft. Pump bearings are held in brackets separating them from the stuffing boxes which are water-sealed to prevent air inleakage.



SECTIONAL VIEW OF MORRIS 3-STAGE HIGH-PRESSURE PUMP



HIGH LIFT PLATT TURBINE PUMP

When necessary to pump against high heads, multistaging is resorted to. In these types the impellers are of the enclosed type, fitted with labyrinth packing rings to prevent leakage from the discharge to the suction side of the impeller, and hydraulically balanced by means of a suction chamber connected by openings through the web to the suction side of the impeller. In addition to this method of balancing, a marine type of thrust bearing provided with a water cooling jacket is employed.

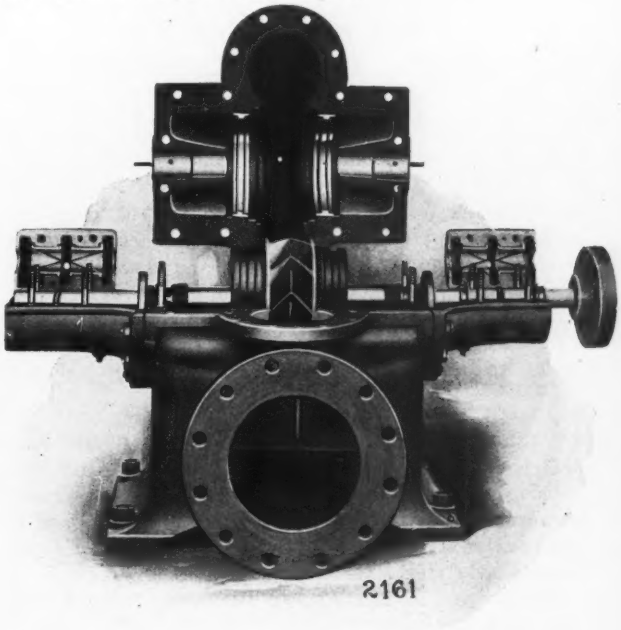
Platt Centrifugal and Turbine Pumps

Double-suction centrifugal pumps, made by Platt Iron Works, have the lower part of the casing cast in one piece, giving strength and rigidity to the construction, while the upper part of the casing is removable without the necessity of breaking the suction or the discharge piping. The rotors of these pumps are especially designed to meet the conditions under which they are expected to work, the type selected being that which from experimental work has proved to be the most efficient. In the view shown here the impeller has a compound curvature.

These pumps may be designed and built for almost any class of service, although it may be out of the ordinary. The capacities range from 5 to 150,000 g.p.m.

Platt high lift and turbine pumps are built for all heads and service conditions up to 700 ft., and are arranged for direct connection to electric motor, steam turbine, steam or gas engine, or for belt drive as may be desired. The number of stages supplied in the pump depends upon the head under which the pump is to be operated. Two styles of diffusers are used, all smaller pumps having the open diffuser, while all large pumps have the closed type.

These pumps are admirably adapted for boiler feeding work, giving an uninterrupted and steady discharge without shock on the pipe system and without the use of air chambers and release valves.



INTERIOR VIEW OF PLATT DOUBLE-SUCTION CENTRIFUGAL PUMP

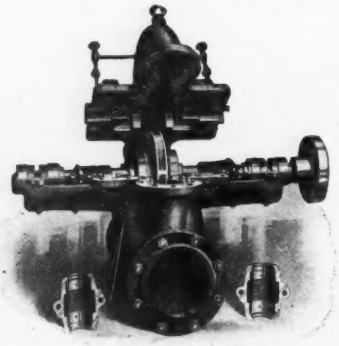
Union Centrifugal Pump

Volute centrifugal pumps made by Union Steam Pump Co., are of both single and multistage types. Pumps of the single-stage type are designed with single-suction impellers for sizes up to and including 6 in., and double-suction impellers from 3 in. to larger sizes. The single-suction pumps are subjected to more or less end thrust, but to overcome this the impellers are hydraulically balanced, the remaining thrust being picked up by a thrust bearing of the marine type on the larger sizes, and thrust collars on the smaller pumps. The single-suction type of impeller is used in single-stage pumps which operate under heads up to and under 75 ft. For greater heads than this the double-suction, single-stage pump is used, which is capable of delivering against 150-ft. heads.

Impellers used with these pumps are of the enclosed type, and machined on the outside and the water pas-

sages are filed smooth in order to reduce friction. The stuffing boxes are not required in any way to support the shaft, being separate from the main bearings of the pump, and are water-sealed to prevent the leakage of air around the shaft.

For heads greater than 150 ft. this company installs a 2-stage turbine pump which is particularly adapted to water-works service, farm service, also for fire pumps



UNION DOUBLE-SUCTION VOLUTE PUMP

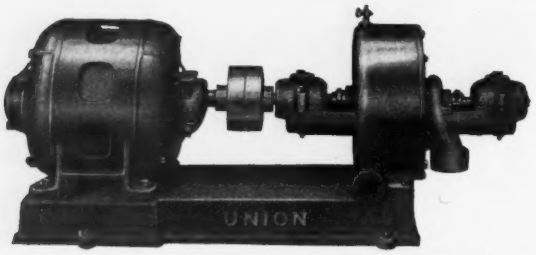
and general service. In this type the water is delivered from the first stage into a return chamber which forms the suction of the second impeller. With the exception of the smallest size, the pump case and bearings are horizontally split, both suction and discharge openings being located on the bottom half of the casing.

In addition to balancing the impeller hydraulically, a thrust bearing of the marine multi-collar type with a centrifugal oiling arrangement is employed. Except in the smallest sizes, thrust bearings are water jacketed.

Centrifugal Circulating Pumps

C. H. Wheeler centrifugal pumps are built in 3 different types, respectively for low, moderate and high speeds. Pumps of the first and second types are usually steam engine driven with or without Rotrex pumps in combination. Pumps of the third are designed for direct conection to steam turbines or motors.

In low and moderate speed pumps the volute is cast

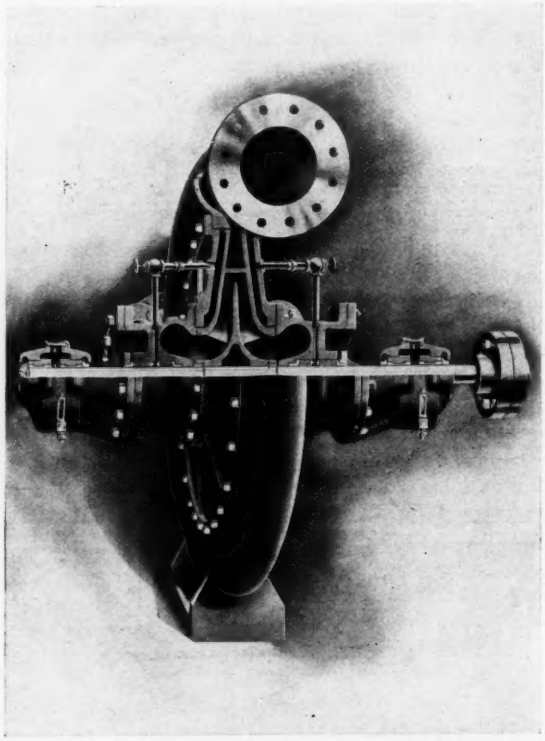


UNION MOTOR-DRIVEN 2-STAGE PUMP

in one piece with discharge opening pointing in any direction desired in the plane of the impeller. This opening is flanged and drilled for piping connections and both sides of the volute are open faced and fitted on close centers with stud bolts to receive the side covers. The impeller is of the enclosed type with vanes shaped to give maximum efficiency for specified conditions, and it is secured on the shaft by means of a key. To prevent corrosion the shaft is covered with brass through the water passages and stuffing boxes, the latter being extra long and fitted with a grooved brass water sealing ring to prevent air leakage around the shaft. The 2 suction heads are connected by a Y-shaped suction branch, the double-suction arrangement being used to eliminate end thrust of the impeller and consequent wear.

The high-speed pumps differ from the lower speed pumps in having a casing horizontally divided. The suction and discharge openings are contained in the lower half of the casing, although the pumps may be reversed end for end in order to run in the other direction.

For handling the water from hot-wells of condensers the C. H. Wheeler Mfg. Co. has designed a special centrifugal pump which operates in 2 stages, thus having only one stuffing box under vacuum instead of 2, also dividing the duty of handling the hot water in a manner



C. H. WHEELER CENTRIFUGAL PUMP IN HALF SECTION

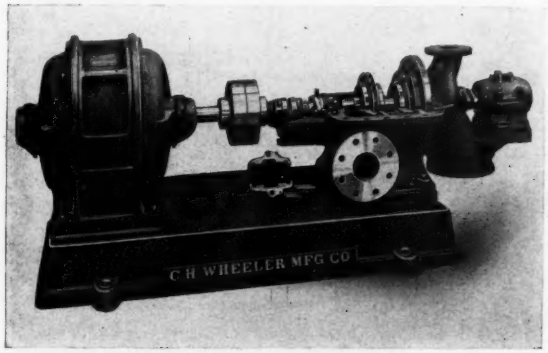
insuring steadiness and uniformity of flow. The efficiency of the stuffing box depends both on the adequacy of its water-sealing and its being kept cold at all times; the usual water-sealing is supplemented by a special arrangement for cooling the gland itself. For this purpose the gland is cast hollow and a stream of cold water is run through it, thereby averting any possibility of the stuffing box losing its water-seal and admitting air through the over-heating.

Thyssen Entrainment Vacuum Pumps

Features of a rotary entrainment pump with the simplicty of a centrifugal pump are combined in the Thyssen vacuum pump made by the C. H. Wheeler Mfg. Co.

In principle the Thyssen pump consists of 2 continuous water films discharged radially through annular

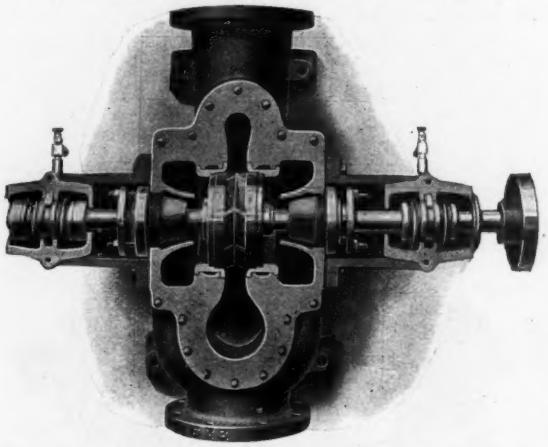
nozzles surrounding the periphery of 2 impellers supplying the necessary entrainment water under pressure. These water films entrain the air through secondary nozzles in which the kinetic energy of the water and vapor mixture is gradually converted into pressure and the mixture discharged against the atmosphere. The entrainment water is supplied from a tank usually located under the pump and circulated through the pump over and over again. The cold entrainment water condenses the water vapor in the mixture coming from the



C. H. WHEELER 2-STAGE CENTRIFUGAL HOT-WELL PUMP

condenser, and as no re-evaporation is possible the entrainment pump serves as a secondary condenser in series with the main condenser.

The casing of the Thyssen pump contains 2 side suction water impellers mounted right and left-hand on one shaft, the water being supplied from beneath and discharged through nozzle rings extending around the periphery of both impellers. The water issues from the discharge nozzles in thin annular sheets and is delivered to the stationary entrainment nozzles converting the



VIEW OF WHEELER CONDENSER ENG'R'G CO.'S PUMP FROM ABOVE

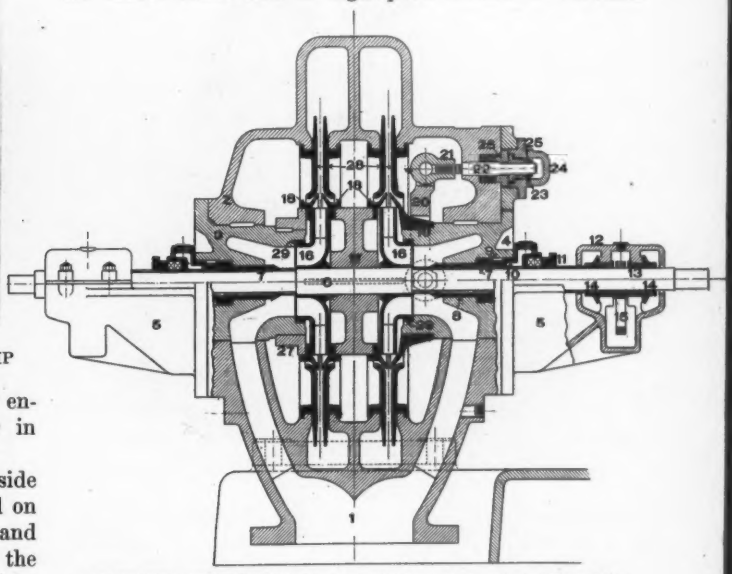
velocity of the mixture into pressure, after which it passes to the volute and discharges in the regular way. The air is admitted through an opening at one end of the pump and upon passing to both sides of each of the discharge nozzles is drawn into and forced through the entrainment nozzles by the velocity of the water.

Thyssen pumps are built in all sizes up to a capacity sufficient to operate turbines of 15,000 kw.

An important feature of this pump is that the water supply is independent of the vacuum in the condenser, i. e., the pump draws its water the same as an ordinary centrifugal pump and fluctuations in vacuum have no effect upon the priming or the continuous operation of the pump.

Wheeler Centrifugal Circulating Pump

For supplying water to condensers the centrifugal pump has many advantages which commend its use, but one of the difficult problems has been to design a pump for direct connection to high-speed motors or turbines



THYSSEN ENTRAINMENT VACUUM PUMP IN SECTION

at the same time have large capacity at low head. The Wheeler Condenser & Engineering Co. has solved this problem by employing in its pumps what is known as a speed impeller. This impeller has a large diameter of eye compared with a small diameter of the impeller which is obtained by shaping the vanes to a form between those of the cylindrical and of the helical impellers. The exact shape of the blades depends upon local conditions; some are built helical, others of the hub type.

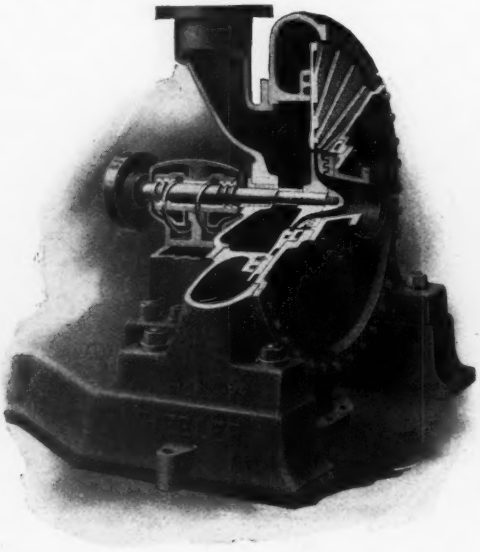
It is customary to run these pumps as one element of a combination auxiliary unit direct connected to turbine or motor shaft. The impeller is of the double suction type. The casing is of the volute shape, split horizontally in a plane through the shaft with suction and discharge connection from lower half of the shell.

Shaft bearings are held by brackets bolted to the pump casing and are of the ring oiling type entirely separate from the stuffing boxes.

Wheeler Turbo Air Pump

The Turbo air pump made by the Wheeler Condenser & Eng'g. Co., is used for removing the air from small impeller in which the water is accelerated. The water enters the eye of the impeller and is thrown out radially at high velocity in a series of small jets issuing from ports around the whole periphery of the impeller. These jets then pass to the second part of the pump, namely, the diffuser, comprising a large number of tapered channels in which the compression of the air

takes place and the velocity is changed into pressure so that the water and air may be discharged to the atmosphere. The air is admitted around the whole circumference of the impeller through the annular space between the impeller and the inner edge of the diffuser channels. The angularity of these channels and the angle at which the water leaves the impeller blade, is such that the jets are broken up into small plugs which pass through the tapered channels. Thus the air is not



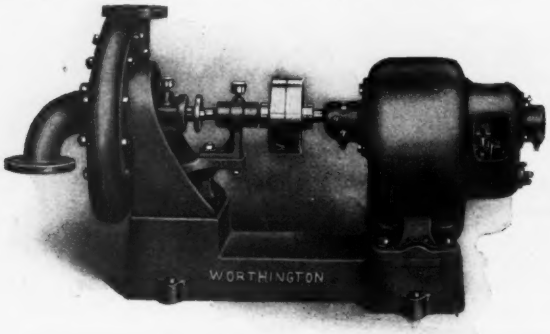
WHEELER TURBO AIR PUMP, TYPE TA

only entrapped by the surface friction of the multitude of jets escaping from the impeller, but is also caught between successive small volumes of water as they enter the end of the tapered channels.

At the inner periphery of the diffusion channel the distance between the successive plugs of water is comparatively large, but decreases as the air is compressed.

Worthington Centrifugal Pumps

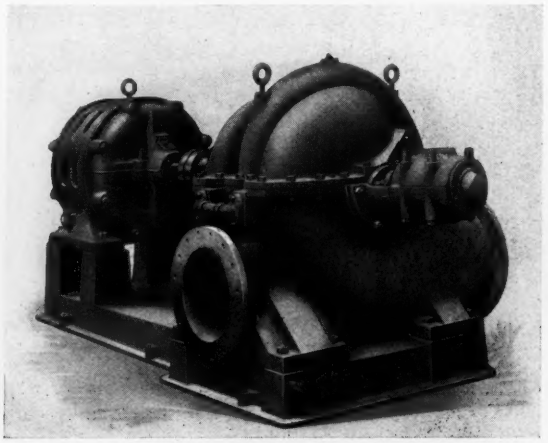
The form of suction head and shaft bearings are the distinguishing features of Worthington single-suction volute pumps which are built for general service and



WORTHINGTON SINGLE-SUCTION MOTOR-DRIVEN PUMP

particularly adapted for motor drive. The suction head is so designed that the water is evenly distributed over the entire eye of the impeller, thus assuring an equal flow through all portions of the impeller. In small sizes 2 bearings support the shaft direct from the pedestal with the casing overhung, in larger sizes, however, the bearings are placed one on each side of the casing, but are entirely separate from the stuffing boxes. These are built in sizes from 1 to 24 in. discharge at 80-ft. head.

Where space is limited the double-suction pump is well adapted as the diameter is smaller for the same capacity. Two types of the Worthington double-suction pump are shown; one is turbine driven (see page 1), has the volute casing with suction and discharge connections cast in one piece to which the heads and bearing brackets are bolted; the other is motor driven and has the casing



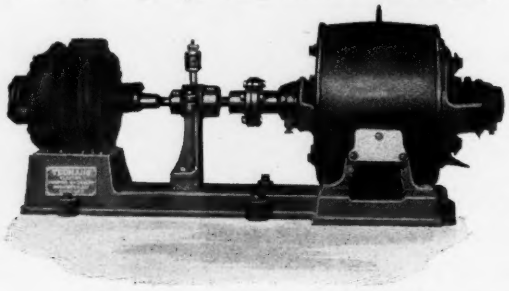
SPLIT CASING TYPE OF WORTHINGTON DOUBLE-SUCTION PUMP

split horizontally in the plane of the shaft with suction and discharge connections on the lower half. The latter design is of particular advantage where space is limited and frequent inspection necessary due to severe conditions as it gives easy access to the interior.

Particular attention has been given to the areas and contour of the water-ways through the impellers and casings of these pumps.

Yeomans Centrifugal Pumps

Yeomans Form A duplex centrifugal sewage ejector consists of a cast-iron sewage receiver with 2 centrifugal pumps connected by piping and valves to the bottom of the receiver, the pumps being located in the dry ejector

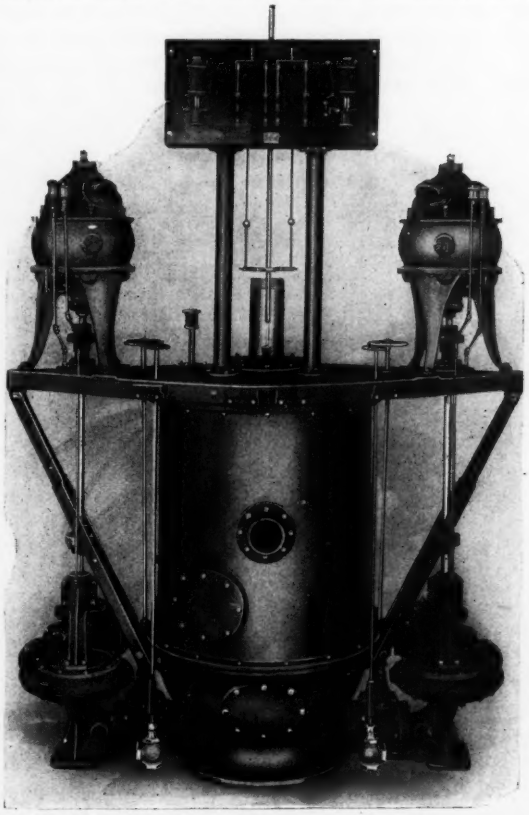


YEOMANS CENTRIFUGAL HOUSE PUMP

pit which contains the receiver. The pumps are direct connected to vertical shaft electric motors mounted on a base plate at floor level which forms the cover for the receiver. The motors are controlled by means of automatic starters actuated by a copper float running

in a pipe casing in the receiver, and so arranged that if the inflow to the ejector exceeds the capacity of one pump, the second unit will cut in automatically. These machines are provided with auxiliary suction connections for pumping water out of the ejector pit if this becomes necessary; 36-in. diameter cast-iron screens in the receiver; high water alarm; forced feed thrust bearings; bronze covered shafts; gate and check valves on the discharge, and gate valves on the suction of each pump. Valves are all located in the ejector pit.

Yeomans electric bilge pumps for handling seepage, drainage, blowoff, etc., are similar in principle to Form A ejectors, being designed with centrifugal submerged pumps suspended by means of flanged pipe hangers from a cast-iron catch basin cover. Motor is mounted on top



YEOMANS DUPLEX CENTRIFUGAL SEWAGE EJECTOR

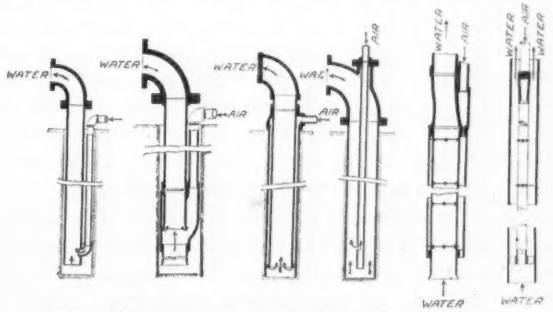
of the basin cover and direct connected to the pump by flexible coupling. The system of automatic control is similar to that of the Form A ejecter.

Yeomans centrifugal house pumps are built in all sizes and in any number of stages for any required capacity and head. They are supplied with direct-connected motors on common cast-iron base, flexible shaft couplings, cast iron or bronze enclosed impellers, as may be required, external ring oiled shaft bearings and water jacketed thrust bearings. They can be used either with elevated gravity tanks or with compression storage tanks and with complete automatic control equipment insuring a constant supply of water with the minimum amount of attention.

The above equipment is manufactured by Yeomans Brothers Co.

Air Lift Pumping

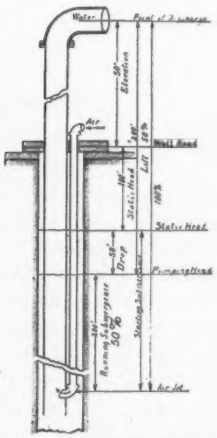
DURING recent years, considerable development has been made in the system of pumping known as the air lift. This method of pumping can be used only for elevating water where the discharge is open to atmosphere. It is not applicable to general service about a power plant nor for pumping water in horizontal pipes except when a special apparatus, known as a booster, is used in connection with the air lift apparatus.



THE ORIGINAL POHLE OR SIDE INLET PUMP
POHLE ANNULAR FOOT PIECE
SAUNDERS AIR LIFT SYSTEM
CENTRAL AIR PIPE SYSTEM
IMPERIAL CLASS V A
IMPERIAL CLASS V C

Theory

THE THEORY of air lift pumping is based upon the fact that a mixture of air and water is lighter than water alone, volume for volume. By submerging the open lower end of a pipe in water, then introducing air a short distance from the lower end, the column of



HARRIS 20TH CENTURY AIR LIFT PUMP
ILLUSTRATION OF TERMS AND PROPORTIONS OF AIR LIFT SYSTEMS

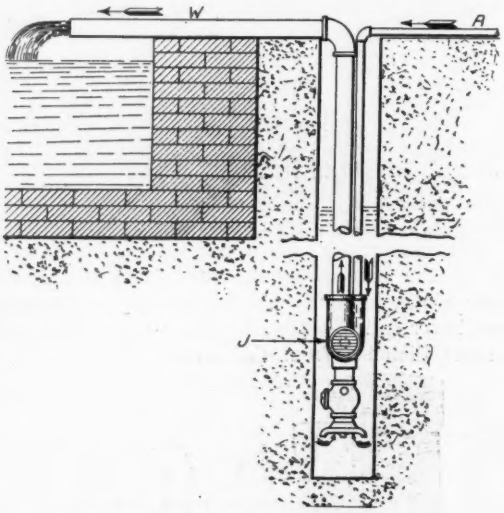
mixed air and water in the pipe will increase in height, due to the decreased specific gravity, until the pressure at the lower end of the pipe, due to the water around it, is equal to the pressure due to the mixture of air and water. To maintain this equilibrium, air must be introduced continuously, for it readily separates from the

water, due to difference in density. The object, however, in pumping is not to maintain equilibrium, but to utilize the height to which the water and air column is raised by discharging it into a receptacle before a balance of the pressure is reached, in this way a continuous flow of water is maintained from the higher pressure outside the pipe to the lower pressure inside the pipe by way of the open lower end.

While originally it was thought that the water and air rose in alternate layers in the pipe, in recent practice best results have been secured by obtaining the most intimate mixture of air and water to the point that it becomes almost foam; in this condition, slip, which is the principal cause of loss in this method of pumping, becomes less.

Arrangement and Foot Pieces

To bring about the desired results under various conditions of installation, several styles of pumps, discharge heads and piping have been devised. As previously stated, the original idea which was brought out by the inventor, Julius G. Pohle, was that alternate layers



THE KOERTING AIR-JET LIFT

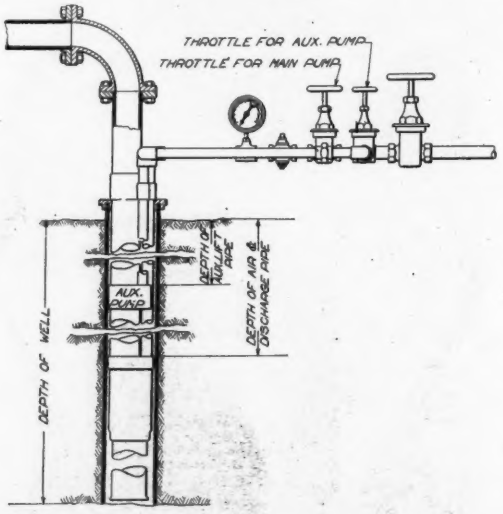
of air and water ascended through the discharge pipe; working on this idea, he devised several types of pumps, 2 of which are shown here; no attempt, it will be noted, has been made in either design to break up the air bubbles, which distinguishes them from modern designs. In the original Pohle or side inlet pump, air and water pipes were placed alongside each other inside the well casing, the air pipe being connected to the water pipe near the bottom by an end piece. This method has been used extensively but is giving way to improved designs.

Pohle's annular foot piece is another adaptation of this system; in this, a special device for connecting the air and water pipes is provided which gives a more even distribution of air in the water pipe. Compressed air fills the annular space surrounding the uptake pipe and is free to enter the rising column of water at all points of its periphery, at the same time acting without obstructing the discharge pipe anywhere.

Where the size of the well does not admit of the use of a side air pipe, the Saunders system may be used. This system consists of an air tight well casing into which the water pipe is lowered, the action being essentially the same as that of the Pohle annular pump. This system is still sometimes used in salt wells with a natural flow, or in wells into which water is pumped to dissolve the salt which is raised as brine.

Reversing the arrangement of the pipes we have the central pipe system, which is used to obtain the greatest possible output for a given size of well casing. The air pipe is suspended inside the casing and its size depends upon the amount of air to be carried, the pressure and the depth of the well. The water and air mixture rises in the casing outside the air pipe.

Coming now to modern designs, we have the Imperial Class V A and the Imperial Class V C, which are modifications of the Pohle annular type and the central air pipe systems, both made by the Ingersoll-Rand Co. In the former, the annular features are maintained, but the air is admitted to the water pipe through small holes which break the air into small bubbles, getting a more



THE COMPOUND AIR LIFT ARRANGEMENT

intimate mixture of air and water. The mixing tube is ½ to 1 in. larger in diameter than the discharge pipe for which it is intended, and a Venturi connection between the mixing chamber and the discharge pipe gives the proper acceleration at this point. This arrangement creates a certain amount of back pressure in the pump, which prevents a sudden rush of air due to the coalescence of the air bubbles and lightening of the discharge column.

The Imperial Class V C system differs from the central air pipe system in the form of the air discharge into the water pipe. The outside casing, or mixing chamber, is a steel tube, and the central air pipe a brass tube, perforated with rings of small holes for the purpose of reducing the size of the bubbles, these rings or bands of holes being spaced so as to give the necessary governor effect. The end of the brass pipe is left open to pass any scale or dirt that may come down.

Harris 20th Century pumps are also designed along the modern idea that best results are obtained with an intimate mixture of air and water, amounting in this case to an emulsion. By a special arrangement in these

pumps, the weight of the discharge column of air and water is carried directly upon the air jet so that once the column is started, it is kept moving at a high velocity to the point of discharge.

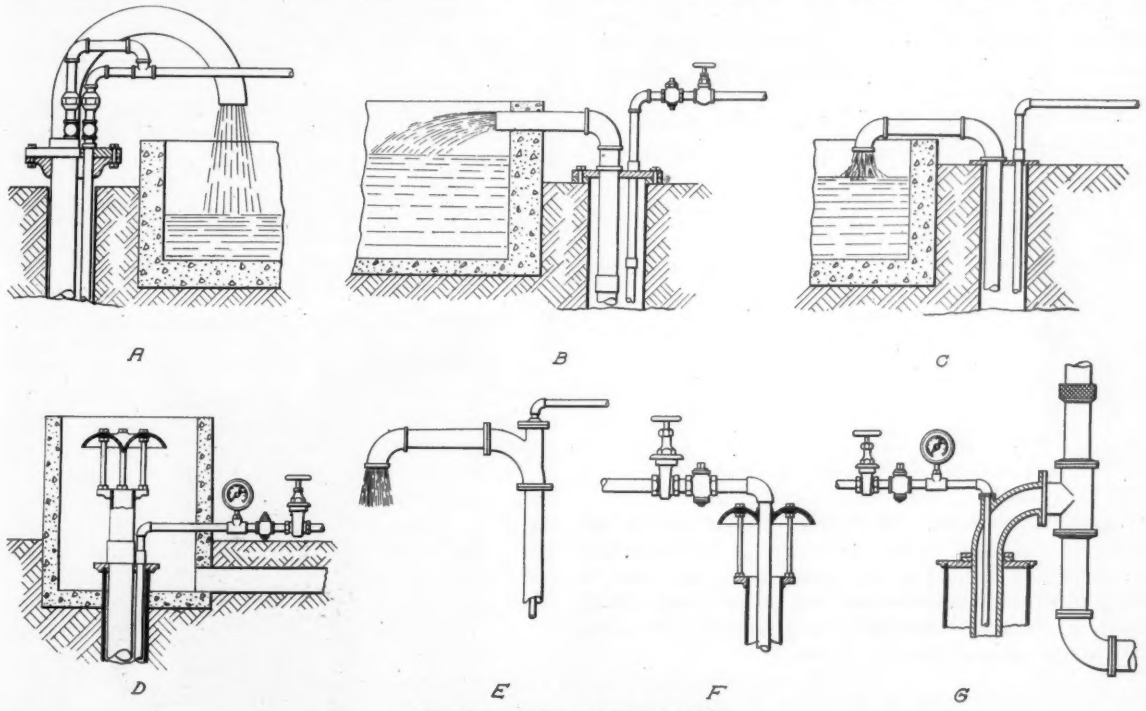
In the Standard Harris 20th Century pump, the air is carried down outside the water discharge pipe and brought up to the center of the pump, discharging the air through a special tube or mixer below the choker, causing a perfect mixture of air and water. An exterior view of this pump, which is made by the Harris Air Pump Co., is shown herewith.

For pumping large quantities of water from wells not having sufficient diameter to admit the Standard pump, the Special Harris pump has been designed, made on the same principle but with the central air pipe system and employing either the well casing proper as the discharge or an additional casing suspended in the well, as may be determined by the conditions.

first turned into the auxiliary pump and, as the head lowers, the regular pump comes into action and the auxiliary pump is gradually turned off.

Discharge Tops

The type of well top and discharge pipe to employ depends upon the system of piping employed in the well and the location of the tank to catch the water. When the tank is close to the well top, a sweeping return bend serves admirably; if the discharge is horizontal, a long radius ell with connected pipe serves the purpose well. When the tank is a short distance away and the discharge is to be down, 2 long radius ells connected by a length of pipe is the proper arrangement. When the tank surrounds the well top, a special umbrella head is attached to the top of the discharge pipe to reverse the flow of the water. All of these arrangements are simple where the water and air pipes are side by side in the well, but where the Saunders or the central air pipe systems are used, special fittings must be employed as indicated in the illustrations.



SEVERAL TYPES OF WELL TOPS

Another form of pump working on the air lift principle is the Koerting air-jet lift, made by Schutte & Koerting Co., in which intimate mixture is obtained by the use of an air jet, the arrangement being as shown herewith.

Compound Lift

In some wells, the static head is at a much higher level than the pumping head, and to start such a well, with but one pump, requires a much higher air pressure than is required to keep the water flowing. An arrangement known as the compound air lift has been devised to overcome this difficulty. It consists of a standard air lift pump with a special auxiliary or starting pump placed so that the submergence, with respect to the static head, will be such as to utilize the maximum pressure of which the compressor is capable without dangerous overload. When starting the well, the air is

Air Boosting

Owing to the principle of operation, when an attempt is made to discharge through a horizontal pipe run or at an angle, the air separates from the water and difficulty is encountered. To overcome this trouble, when it is desired to deliver water to an elevated tank at some distance from the well, the air lift booster has been devised. It is the object of the booster to force the solid water from the well horizontally and vertically, the air being separated from the water and its pressure utilized to force the water to the desired point. The work to be done by the booster, represented by the lift and friction head, should not exceed 25 per cent of the total working air pressure in the air lift pump.

In the diagram is shown the arrangement of air lift pump and booster piped to deliver to an elevated tank while another view shows an outside view of the Harris booster. The booster is placed directly over the well so that the pump discharges into it vertically. The air separates out of the water and the pressure of the accumulating air increases until it is sufficient to drive

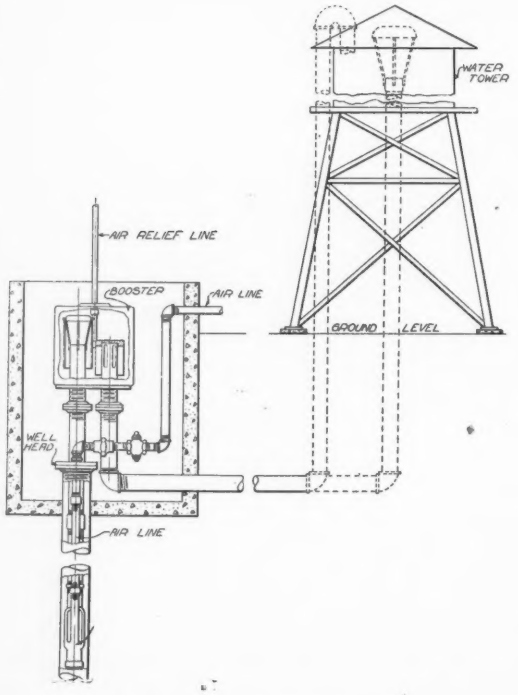


DIAGRAM OF AIR LIFT PUMP AND BOOSTER

the water to the tank. The amount of air within the booster is controlled by the water level. An automatic valve operates so that, as the water rises, the valve is closed and the pressure is built up in the booster, and vice-versa, as the water falls the valve is opened to allow air to escape from the booster.

Proportions of Air Lift Wells

Before taking up the calculation of power required and proportions of air lift piping, a clear understanding of the terms used must be obtained. Referring to the illustration: Static head is the distance from the surface of the ground to the standing level of the water in the well when not pumping. Drop is the distance the water recedes from the static head when the well is delivering water. Elevation is the distance above the ground surface to which it is desired to deliver the water. Lift consists of the static head plus the drop plus the elevation. Submergence is the distance the air pipe is submerged below the level of the water in the well. There are 2 classes of submergence, starting submergence, which is temporary, and running submergence, which is the important factor in any pumping proposition. It is usually expressed as a percentage of the total length of the water column from the point where the air is introduced to the point of discharge.

Necessary percentage of submergence varies in accordance with the lift, low lifts requiring proportionately more submergence than high lifts. The range of these percentages is found within the following limitations: For a lift of 20 ft., 66 per cent; for a lift of 500 ft., 41 per cent.

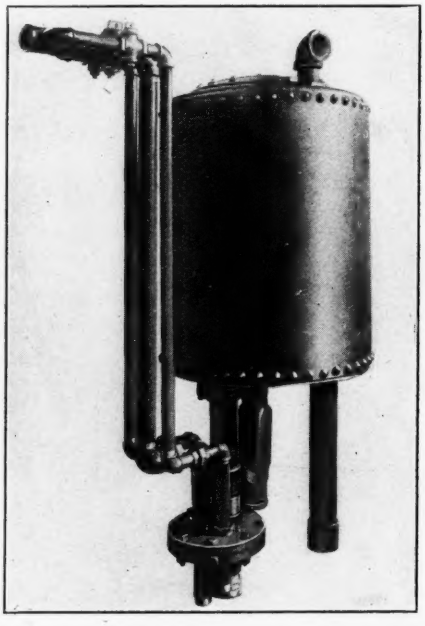
TABLE OF WELL PIPE SIZES

Well Casing In.	Side Inlet			Center Air Pipe	
	Water Pipe	Air Pipe	Capacity G.P.M.	Air Pipe	Capacity G.P.M.
3½	--	--	--	1¼	115
4	1½	¾	25	1½	150
4½	2	1	50	--	---
5	2½	1	75	2	240
6	3	1¼	105	2	360
7	3½	1½	145	--	---
8	4	1½	190	--	---
9	5	2	300	--	---
10	6	2	425	--	---

Knowing the total lift and running submergence, the approximate amount of free air required can be calculated from the following formula:

$$V = L \div (\text{Log}\,[(S + 34) \div 34] \times C)$$

Where V = Volume of free air to raise 1 gal. of water.
L = Total lift in feet.
S = Running submergence in feet.
C = constant found in the following table.



OUTSIDE VIEW OF HARRIS BOOSTER

Lift in feet (L)	Constant
10 to 60 inc.	245
61 to 200 inc.	233
201 to 500 inc.	216
501 to 650 inc.	185
651 to 750 inc.	156

The necessary pressures can be calculated from the following:

Starting pressure = (Depth of pump or foot piece in well less the static head, or starting submergence) × 0.434.

Working pressure = (Depth of pump or foot piece in well less the pumping head, or running submergence) × 0.434 + friction in pipe + 2 lb. back pressure in pump.

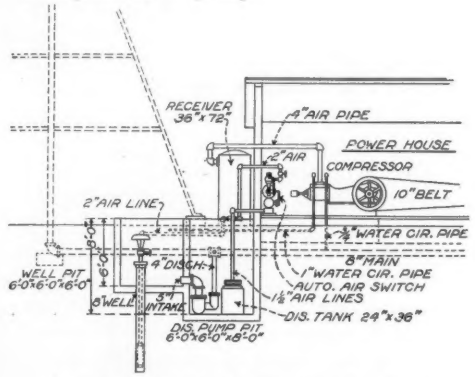


DIAGRAM OF AIR LIFT PUMPING PLANT

These formulas have been worked up into the accompanying table giving the lift, air pressure, ratios of submergence, volume of air required and horsepower of compressor.

Advantages and Precautions

The distinct advantages of air lift pumping are that no moving parts are below the ground surface, all operating machinery for a number of quite widely scattered wells can be located in one plant with air transmission lines to the various wells and the flow of the water can be controlled by the engineer in the plant. The equipment consists of an air compressor located at any convenient point where installation expense and transmission losses are not too great, an air receiver, air transmission pipes to the wells, the pumps proper and the water piping and storage systems. A typical diagram of such a pumping station is shown herewith, illustrating, however, for simplicity only one well.

In laying out a plant, it is well to plan the locations of the wells and the system of piping carefully so as to have as few bends as possible in all piping, for all unnecessary bends and valves add friction and cause losses. The size of piping is also important, and knowing the volume of air or water to be conducted, the proper size can be selected from tables. Where the distance from the compressor to the well is short, it is sometimes of advantage to pipe the air, after it has separated from the water, back to the compressor, as at G, thus taking advantage of its reduced temperature.

COMPARATIVE COSTS OF PUMPING WATER BY AIR LIFT AT VARIOUS PUMPING STATIONS OF ST. PAUL

Pumping Stations	Total Gallons Pumped	Total Lift in Feet	Cost of Raising 1,000,000 Gallons One Foot			
			Salaries	Fuel	Waste Oil and Repairs	Total
McCarron, high service	2,619,949,600	140	$0.0232	$0.0211	$0.0055	$0.0498
McCarron, air lift	885,528,224	77	0.0233	0.0667	0.0029	0.0929
Madson well plant	216,530,283	196	0.0099	0.0918	0.0008	0.1025
West Side, high service	97,829,280	215	0.0953	0.0944	0.0158	0.2055
Vadnais Lake	959,632,500	34	0.0598	0.0976	0.0161	0.1735
Centerville	3,336,073,381	35	0.0267	0.0448	0.0089	0.0804

THEORETICAL HORSEPOWER FOR COMPRESSING AIR

Gage Pressure to which Air is Compressed.	Horsepower per cu. ft. of Air per minute. Single Stage.	Horsepower per cu. ft. of Air per minute. 2-Stage.
10	0.036	
20	0.063	
30	0.085	
40	0.104	
50	0.120	
60	0.134	
80		0.131
100		0.158
130		0.179
160		0.198
200		0.217

Care must be taken, however, that no water gets to the compressor, and it is well to place a separator in the return air line.

The approximate sizes for well piping as given by C. M. Wetherell in the Compressed Air Magazine are embodied in the accompanying table.

FREE AIR REQUIRED AT VARIOUS RATIOS OF SUBMERGENCE TO LIFT

Lift	Ratio of Submergence to Lift																	
	25% 1/3 to 1		33⅓% 1/2 to 1		43% 3/4 to 1		50% 1 to 1		55% 1-1/4 to 1		60% 1-1/2 to 1		66⅔% 2 to 1		70% 2-1/2 to 1		75% 3 to 1	
in Feet	Free Air	Working Pres.	Free Air	Working Pres.	Free Air	Working Pres.	Free Air	Working Pres.	Free Air	Working Pres.	Free Air	Working Pres.	Free Air	Working Pres.	Free Air	Working Pres.	Free Air	Working Pres.
20							.408	9	.349	11	.296	13-1/2	.241	18	.207	22-1/2	.186	27
30							.449	13-1/2	.382	17	.334	20	.277	27	.243	34	.220	40-1/2
40							.475	18	.416	22-1/2	.369	27	.311	36	.274	45	.251	54
50							.522	22-1/2	.449	28	.403	34	.344	45	.306	56	.272	67-1/2
60							.556	27	.487	34	.436	40-1/2	.374	54	.335	67-1/2	.308	81
80							.657	36	.573	45	.525	54	.458	72	.412	90	.382	108
100					.855	34	.724	45	.643	56	.588	67-1/2	.515	90	.468	112-1/2	.435	135
120					.92	40-1/2	.79	54	.707	67-1/2	.646	81	.570	108	.523	135	.486	162
140					.988	47	.852	63	.768	79	.701	94-1/2	.626	126	.575	157-1/2	.536	189
160					1.05	54	.913	72	.825	90	.76	108	.679	144	.628	180	.586	216
180					1.113	61	.971	81	.88	101	.815	121-1/2	.73	162	.676	202	.634	243
200	1.81	30	1.442	45	1.172	67-1/2	1.028	90	.935	112-1/2	.867	135	.78	180	.724	225	.678	270
250	2.12	38	1.725	56	1.42	84	1.25	112-1/2	1.155	141	1.069	168	.97	225	.898	282		
300	2.295	45	1.895	67-1/2	1.63	100	1.4	135	1.305	169	1.14	200	1.093	270	1.02	338		
350	2.47	53	2.05	79	1.77	118	1.569	157-1/2	1.425	197	1.335	236	1.200	315	1.125	394		
400	2.65	60	2.22	90	1.87	135	1.67	180	1.615	225	1.455	270	1.333	360	1.25	450		
450	2.82	68	2.37	100	2.00	152	1.805	205	1.67	253	1.578	304	1.445	410	1.385	506		
500	2.97	75	2.52	112-1/2	2.115	169	1.94	225	1.792	281	1.700	338	1.56	450	1.467	562		
550	3.65	83	3.11	128	2.665	185-1/2	2.41	247-1/2	2.24	309	2.12	371	1.98	495				
600	3.82	90	3.25	135	2.81	205	2.55	270	2.395	337-1/2	2.255	410	2.09	540				
650	4.00	98	3.45	146	2.97	219	2.75	292-1/2	2.545	365-1/2	2.41	438	2.205	585				
700	4.97	105	4.27	157-1/2	3.69	236	3.38	315	3.15	394	3.00	472	2.765	630				
750	5.18	113	4.46	169	3.86	256	3.53	337-1/2	3.34	424	3.12	512	2.900	675				
800	5.40	120	4.64	180	4.03	270	3.70	360	3.48	450	3.29	540	3.100	720				
850	5.58	128	4.82	191	4.20	287	3.86	382-1/2	3.62	478	3.44	574	3.19	765				
900	5.76	135	5.00	202-1/2	4.37	304	4.01	405	3.75	506	3.49	608	3.33	810				
950	5.97	143	5.18	214	4.50	322	4.17	427-1/2	3.92	535	3.73	644	3.47	854				
1000	6.17	150	5.36	225	5.19	337-1/2	4.33	450	4.07	562-1/2	3.87	675	3.62	900				

Pressure Pumping Systems

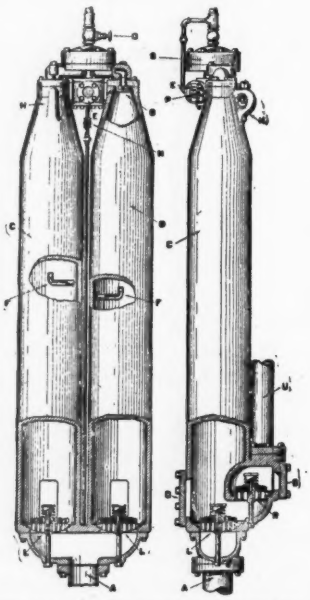
The Emerson Steam Pump

A study of the sectional view of the Emerson standard pump will give a clear understanding of its construction and principle of operation.

It consists of 2 vertical chambers, B and C, cylindrical in form and cast together at the bottom. Each chamber has at the bottom a suction valve L opening upward from a common chamber which suction pipe A enters; and a discharge valve R opening upward into a common chamber, from which discharge or delivery pipe U extends.

On the top of each chamber is a flange with baffle plate G cast to its lower or inside face, and located opposite the steam port which passes through the flange. This baffle plate operates to distribute the steam evenly to the 2 chambers and to prevent it from agitating the water therein. The top side of the flange has a ground ball joint to which the main steam chest S is attached.

Condenser nozzle F, made of gun-metal bronze and screwed firmly into the wall of each chamber from the

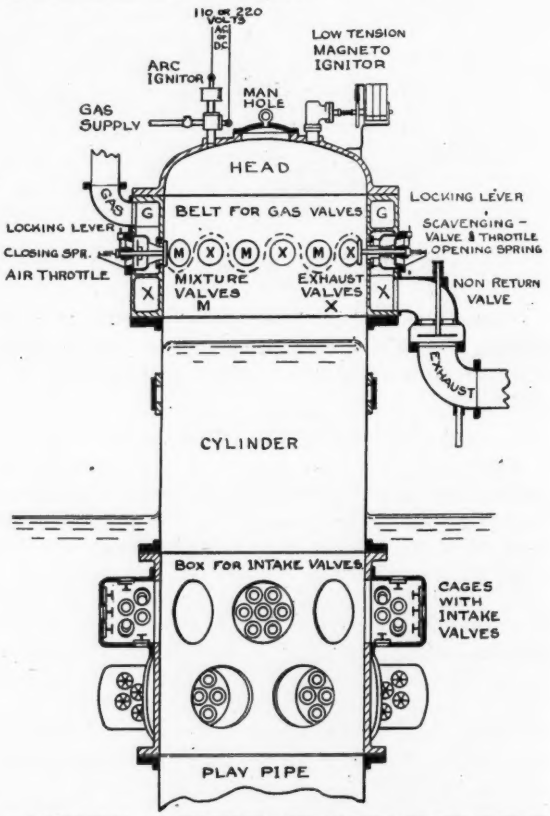


SECTIONAL VIEW OF THE EMERSON STANDARD STEAM PUMP

outside, is connected with the bottom of the opposite chamber by an extra heavy pipe into which a check valve opens upward. As the pressure in the chambers alternates, sufficient water will be injected through nozzle F into the opposite chamber to condense the steam therein, and form a vacuum.

Small air check P, attached to each chamber at the top and opening inwardly, admits a small quantity of air while the chamber is filling with water. The air thus admitted fills the clearance space at the top of the chamber and, being under pressure, places a stratum of air between the steam and the water, thus preventing premature condensation.

Globe valve O, just above steam chest S, is used to regulate the amount of steam that enters the pump. Steam chest S has 2 ports, one leading to each chamber. A flat rotary slide valve, entirely enclosed in the steam chest, admits steam through these ports to the 2 chambers alternately. Thus one chamber fills with water while the other is discharging, and with each revolution of the slide valve there is one complete filling and emptying of both chambers. This slide valve is driven by a small 3-cylinder engine E, rigidly attached to the under side of steam chest S. The engine crank shaft extends into steam chest S in the center of the bearing around which the slide valve rotates, and a positive geared connection is made between the engine and the valve by cut gears of steel and bronze of such ratio that the engine will run faster than the valve.



ARRANGEMENT OF CYLINDER AND VALVES OF HUMPHREY GAS PUMP

The exhaust pipe passes down between the pump chambers and into the common suction chamber, where exhaust steam from the engine condenses.

Emerson steam pumps are built by the Emerson Pump & Valve Co.

Humphrey Gas Pump

The general construction of the Humphrey gas pump may readily be understood by a study of the accompanying figure, which shows the arrangement of cylinder and valves.

Mounted upon a play pipe, which as a rule is securely tied into a concrete pillow or pier and connected to a suitable discharge pipe, is a cylindrical box fitted with water intake valves of "hat" unit form of construction and into which valve seats of manganese bronze are forced.

Just above the water valve box and forming part of the combustion chamber is placed the power cylinder, consisting of a length of riveted pipe.

The belt for gas valves is a double-walled steel casting through which openings are provided for the gas and air mixture, and exhaust valves. In order to have an even distribution of flow of gases into and out of the cylinder, these openings are generally arranged in groups separated by a dividing wall which runs around the annular space between the outer and inner walls of the belt as represented by the dotted lines passing below and above openings marked X and M respectively. The belt is thus divided into an upper chamber provided with a rectangular opening, to which the gas pipe is connected, and a lower chamber with 2 larger but similar openings faced and studded for attaching the nonreturn valves and the exhaust pipe, which are led downward to allow any water carried with them to drain off.

Upon the employment of an ingenious interlocking mechanism depends the entire operation of this pump. During the expansion following the power stroke it is necessary that the mixture valves be locked and the exhaust valves unlocked, and during the charging stroke that the exhaust valves be locked and the mixture valves unlocked. This is accomplished by a sprocket roller chain stretched around the belt above the gas valves and carrying lugs which engage the locking levers of the exhaust valves in one direction and those of the mixture valves in the other direction. With each explosion the chain and lugs are moved against the upper ends of the exhaust valve lock levers, but the valves do not open until the pressure is below atmosphere. On the following "cushion" the chain is moved in the opposite direction which disengages the exhaust valve levers and allows the valves to be locked by gravity, and engages the mixture valve lock levers, moving them to unlock position from the gravity lock previously assumed.

The chain is moved by 2 small hydraulic engines called "shifters," each consisting of a spring loaded horizontal piston in a single-acting cylinder actuated by the play pipe pressures. The shifters also serve to actuate the timers or contact makers, for the electrical ignition system.

Latta-Martin Displacement Pump

The standard displacement pump of the Latta-Martin Pump Co., shown in the accompanying illustration, is designed for submergence in water or other liquid to be handled. The 2 cylinders placed side by side and connected to common inlet and discharge connections, fill by gravity through foot valves 64, and the liquid is displaced alternately from each cylinder by the admission of compressed air through the main valve mechanism at top of pump.

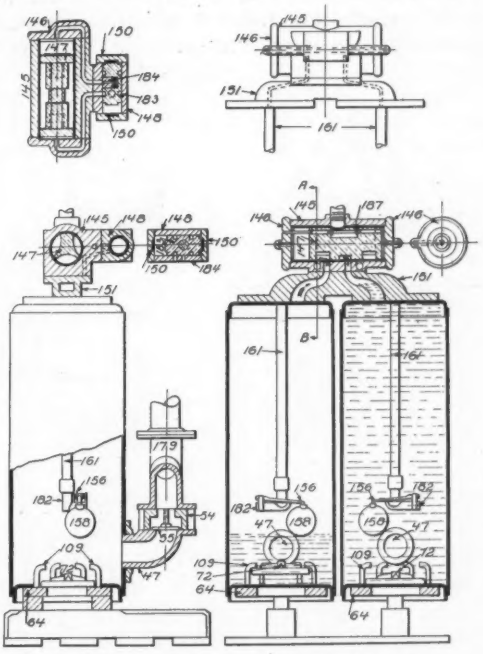
When in the position shown, the left-hand cylinder has been emptied and is exhausting through valve in the direction of the arrows; at the same time, live air is being admitted through valve to right-hand cylinder and is displacing water out through discharge opening 47, passing through discharge check, 55.

When the water has been expelled from the cylinder, small copper float 158 drops, pulling down float lever 156, which uncovers a small port at 182. The compressed air which has already been used in displacing water, enters the small port 182, passing up float pipe 161, attached to crosshead casting 151 and engages an air passage through crosshead casting and main valve casting, registering with a corresponding passage in auxiliary valve casting.

The passages referred to in auxiliary valve are crossed so that air passing up from float valve in right-hand cylinder leads to left-hand end of auxiliary and vice versa, the main valve and auxiliary valve thus always moving in opposite directions.

It will be observed that the position of main valve 147 is to the right, the position of the auxiliary valve therefore to the left, and as stated above, live air is entering right-hand cylinder of pump, while the left-hand cylinder is exhausting; when the right-hand cylinder is emptied and air passes up through float pipe 161 as described, it leads to left-hand end of auxiliary valve and forces it to the right.

When in this position, air at the left end of main valve is released and main valve moves instantly to left and is seated against the cap 146. This cap is inlaid with a composition which forms a perfect seat and prevents further escape of air. When auxiliary valve is to the right as above, it will be noted that the release passage from right-hand end of main valve is closed by cutoff plug 184 in auxiliary valve. The cutoff plug is fitted transversely in a milled recess in auxiliary valve and contains a small air passage through its center. When brought in contact with either of the release ports from main valve air enters the small passage and by reason of its larger exposed area at bottom is forced tightly against release port, making a perfectly leakless fit, yet free and easy moving. The 2 release ports or passages leading to either end of the main valve are thus alternately opened and closed by the movement of the auxiliary valve. The positive movement of the main valve is facilitated by a small spool valve 187, which is loosely fited at top of the annular space around main valve. When air is released from one end of main valve there is a decreased pressure at that end, and the small spool



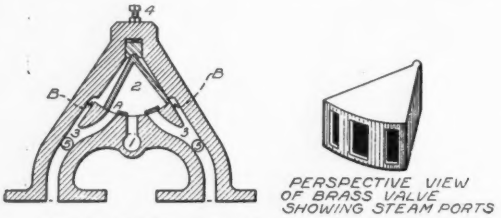
LATTA-MARTIN DISPLACEMENT PUMP

valve is drawn to a seat at such end, thus preventing an escape of air through release port, and at the same time when drawn to a seat in one direction it leaves its seat at opposite end and permits a free inlet of air to end of main valve, producing a positive movement, the release port at such end of main valve being closed by the cutoff plug in auxiliary valve.

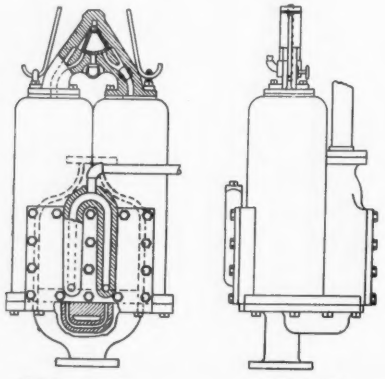
The Nye Steam Pump

This pump, built for the handling of water, sand, coal, peat, crushed rocks, etc., consists, as shown, of 2 cast cylinders joined by common steam, suction and discharge connections.

Steam enters steam-line connection 1 and is led directly into brass control valve 2. In the position shown, steam, by way of port A and passage 3, enters the left-hand cylinder, forcing out its contents. When the water has fallen to the level of the suction opening near the bottom of the cylinder, the other or right-hand cylinder has almost filled, and the pressure is due to this rising column of water forces 2 jets of cold water into the steam-filled chamber. This condenses the steam and



STEAM VALVE DETAILS, NYE STEAM PUMP



FRONT AND SIDE ELEVATIONS OF NYE STEAM PUMP

forms a vacuum, which allows the pressure of the atmosphere to force water through the suction pipe, filling the chamber from below, and at the same time causes valve 2 to shift to the left. This action is augmented by the pressure existing in the right hand chamber acting through passages 3 and B, and results in shutting off of the steam in the left-hand chamber and its admission into the right-hand chamber. The water contained therein now being acted upon by the pressure of the steam is forced out through the discharge while at the same time the left-hand chamber is due to the vacuum, receiving a fresh supply preparatory to discharge.

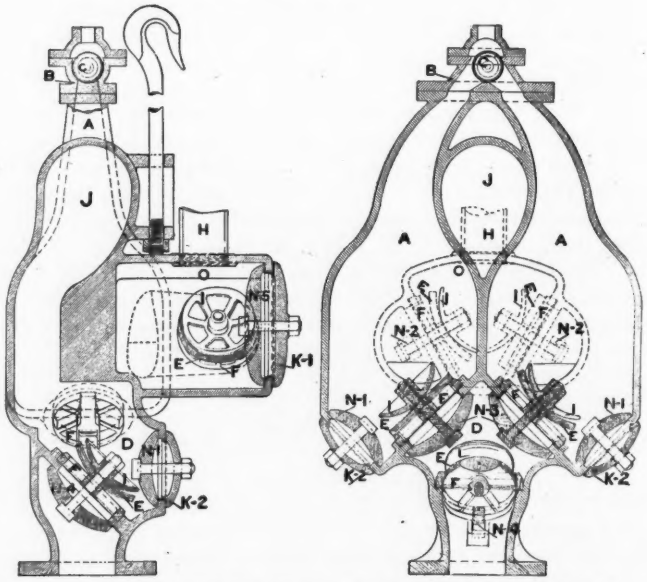
The Nye steam pump is built by the Nye Steam Pump and Machinery Co.

Pulsometer Steam Pump

From the illustrations it will be seen that the Pulsometer, which is the product of the Pulsometer Steam Pump Co., consists of a hollow one-piece casting, having 2 bottle-shaped chambers (AA) with their necks communicating at the top, and each opening into the outlet chamber, O, through a check valve. An air chamber, J, connects with the suction inlet and serves to cushion the incoming pulsations.

Near the top of each pumping chamber is an inwardly opening air check valve. These air valves automatically admit a small quantity of air at each pulsation, at the moment the vacuum is formed. This layer of air serves 2 purposes: First, it cushions the inrushing water; secondly, it forms what may be termed an air piston, separating the steam and water.

The operation of the pump is as follows: Steam from the boiler is admitted to the pump at the top, and enters either the right-hand or the left-hand chamber, A, depending upon the position of the steam valve C. This steam valve is a ball which is free to roll either to the right or to the left, and forms a steam-tight joint with whichever seat its rests upon.



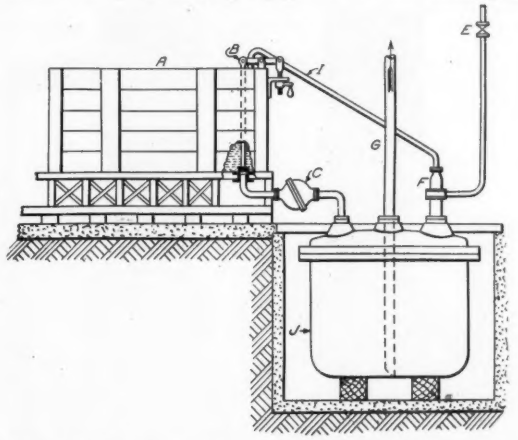
SECTIONS THROUGH PUMPING AND DISCHARGE CHAMBERS OF PULSOMETER STEAM PUMP

As shown in the sectional view, the steam would pass to the left-hand chamber, A, which we will assume is full of water. The pressure of the steam depresses the surface of the water without agitation, due to the air cushion mentioned above, forcing the water out of chamber A, through a passage (not shown in the drawing) and a check valve, F (dotted), into the discharge chamber, O, thence to the discharge pipe, H. The moment the water falls to the level of the opening leading to the discharge chamber, the even surface of the water is broken up and, owing to the peculiar form of the pump chambers, the water and steam are thoroughly churned up and brought into intimate contact, causing instant condensation of the latter. This forms a vacuum in the left-hand chamber which, assisted by a slight upward

pressure in the right-hand chamber, immediately pulls the ball valve, C, over to the left hand seat, shutting off the steam supply. The vacuum in the left hand chamber now draws up a new charge of water through the suction pipe. While the left-hand chamber is filling up, that on the right-hand is emptying. This completes the cycle.

Bihn-Jones Automatic Air Device

Liquid from tank A, regulated by plunger and seat B, passes through a filling pipe and Any Position check valve C into blow-case J. When this case is filled, air device F opens compressed air ports, and closes the exhaust air ports, which are contained therein, simultaneously closing the check valve and forcing the liquid up discharge pipe G to its destination. When the contents of the blow-case are entirely discharged, a portion of the spent air follows through the discharge pipe, clearing it completely. The air device now closes the compressed air ports and opens vent I to allow the remaining spent air to pass through pipe G to the atmosphere.



METHOD OF USING BIHN-JONES AUTOMATIC AIR DEVICE

During operation of filling and discharging, compressed air valve E remains turned on full, but device F prevents consumption of air except during discharge. By adjusting plunger B, which is provided with a thumb screw arrangement, the time required to fill the blow-case can be regulated so that a definite quantity can be automatically discharged in any specified time.

Bihn-Jones automatic apparatus for lifting liquids is manufactured by Schutte & Koerting Co.

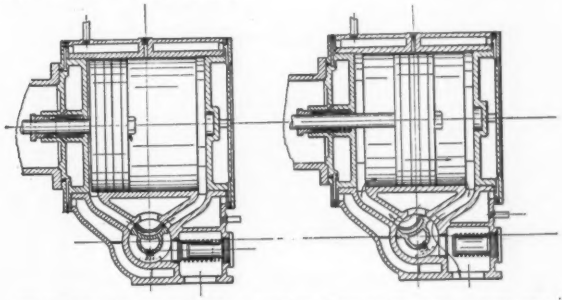
Pumps for Special Uses

DRY-VACUUM pumps for removing non-condensable gases and vapors at high vacuum are practically air compressors working at low pressure, and are usually single stage. They have the smallest possible clearance and in some cases have water sealed valves with the suction placed below the bore of the cylinder; in other cases where only non-condensable gases are to be handled having a regular compressor cylinder, oil-lubricated.

To control suction, a positively-driven Corliss or slide valve is frequently used, a poppet valve being used on the discharge in addition. Such a construction is shown in the illustration of the dry vacuum pumps made by the American Steam Pump Co. In the left-hand view the oscillating valve is in central position, and is on the point of opening the left end of the cylinder for inlet and the right-hand for discharge. The flash port through the valve is for the purpose of releasing the compression pressure at the left end to avoid re-expansion of this gas during the suction stroke, which would reduce the capacity of the pump cylinder. The valve has turned so that the left-hand side is cut off from the discharge opening so that none of the air can back up from the receiver into the suction side, and the poppet valve at the left of the oscillating valve is closed.

The oscillating valve turns to the position shown in the right hand view, and air is drawn into the left-hand end of the cylinder and compressed in the right-hand end until the pressure is sufficient to open the spring-controlled poppet valve, when this poppet valve opens and the gases and vapor are forced out into the atmosphere.

In the Cameron Vacuum Pump, made by A. S. Cameron Steam Pump Works, steam and vacuum ends mounted on a single cast-iron bed plate are tied together by heavy rods bolted to lugs in the ends of the cylinders. These pumps are provided with flywheels and the steam end controlled by plain D slide valves driven from eccentric on the crank shaft.

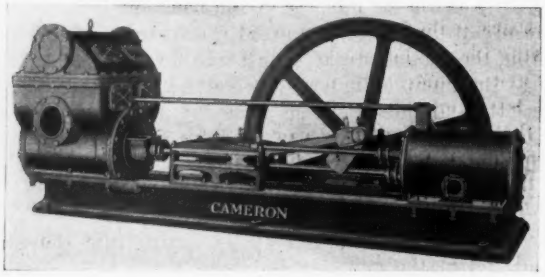


SECTION OF AMERICAN DRY-VACUUM PUMP CYLINDER

Imperial high-vacuum pumps as made by the Ingersoll-Rand Co., are of duplex type, following in general design the Imperial air compressors. Intake valves are of the Corliss type placed in the cylinder head to reduce clearance. This valve is positive and quick in action, independent of the cylinder and intake pressure, hence keeps these pressures as nearly equal as possible. Large direct intake ports and water-jacketed valves tend to cool the incoming gases. Discharge valves of the direct-lift poppet type are placed in the bottom of the cylinder head so that entrained moisture or water is removed, and clearance is reduced by making the valve partially fill the port in the cylinder head. Discharge passages are also water jacketed. Cylinder heads are kept tight by tie bolts passing from head to head and cylinder and heads are completely water jacketed to remove the heat of compression. The duplex arrangement is practically 2 identical units united by a common frame with cranks at 90 deg., so that, if desirable, one connecting rod can be removed and half the machine operated at rated speed, giving half capacity.

In the Mullan displacement vacuum pump, made by the C. H. Wheeler Mfg. Co., which is double acting and of valveless type, the piston operates to create a vacuum until near the end of its travel, when it uncovers a series

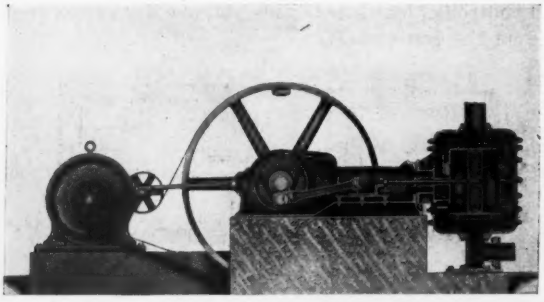
of ports located around the middle of the cylinder. Through these, vapors are drawn through the suction space, discharge valves only being used of Gutermuth flexible metallic type, mounted on stems bolted to each



CAMERON FLYWHEEL VACUUM PUMP

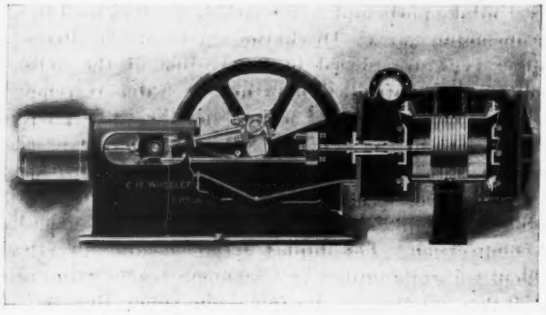
end of the valve deck. These consist of a plate of phosphor bronze or special steel of high tensile strength and elasticity, coiled at one end, flattened and held in a flattened valve stem, the other end left flat to serve as the flap of the valve. The valve stem is adjustable to give the desired tension.

For removing air and water vapors only on the wet



SECTIONAL VIEW OF IMPERIAL DUPLEX VACUUM PUMP

and dry systems a small amount of water is admitted into the suction to reduce vapor tension and absorb the heat generated by compression, also to lubricate and seal the piston and discharge valves. Large water spaces are arranged outside the cylinder head with a common outlet above the cylinder, and being filled with water keep the discharge valves completely submerged at all times.

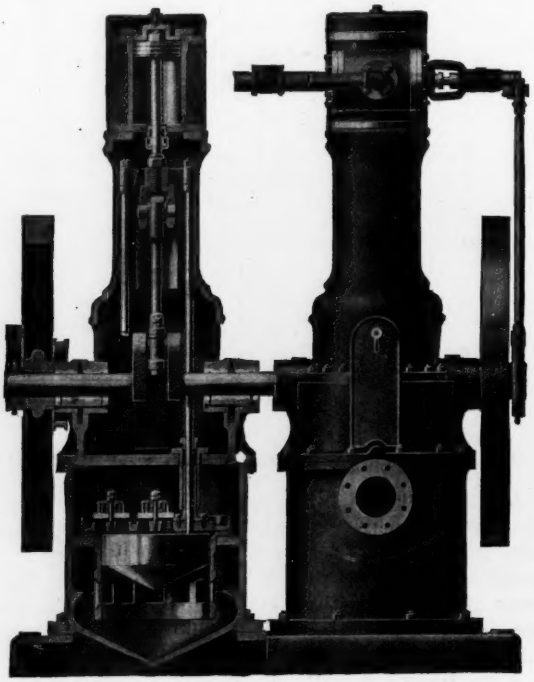


C. H. WHEELER MFG. CO. ROTATIVE DRY-VACUUM PUMP

In the Wheeler-Edwards Pump, made by the Wheeler Condenser & Engineering Co., condensed steam flows by gravity into the base of the pump, and upon the descent of the conical bucket is projected through the ports into the working barrel above. At the same time as the bucket opens the ports, air flows into the pump due to the reduced pressure following the down stroke and to the aspirating effect of the water projected through the ports. As the bucket rises, it closes the ports and sweeps the air and water before it, discharging the mixture through valves at the top of the barrel. The valve deck has ribs between the valves and a lip around the outer edge so that each valve is water sealed independent of the others and can be tested for tightness.

Deep Well Pumps

Special pumps adapted for raising water from deep wells are composed of the head, and the pump barrel proper, the former being of power-driven type, or with a vertical, direct-acting steam cylinder, and the lower end being usually shell made either of brass tubing or bored from a brass casting, and the plungers or buckets having cup leather packing and valves of ball or clapper type.



SECTION OF WHEELER-EDWARDS AIR PUMP

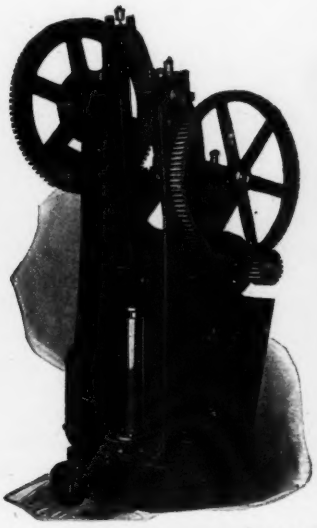
For the more efficient types a displacing plunger is used, as shown in the cross section of the American Well Works deep well double-acting pump, so that the pump operates on both up and down strokes. On the up stroke, which is the condition shown, the foot valve is lifted so that water flows through it to fill the space directly above the foot valve, and at the same time the large bucket, rising, forces water through the upper disk valve into the discharge pipe above. On the down stroke water flows up through the hollow rod, around the outside of the inner plunger, and through the valve in the bucket to fill the space between the bucket and the upper disk valve. At the same time the bucket, traveling downward, forces the water from the space between foot valve and bucket into the hollow inner plunger and out through the ball valve at the top into the discharge pipe.

In another type of pump made by the same company 2 buckets are used, one of them having a hollow rod through which the solid rod of the second works. The buckets move in opposite directions, one rising while the other falls, and each bucket doing half the work of the lift.

Deep well heads are made by the Deming Co., in both horizontal and vertical form, the horizontal head working through a steel walking beam which receives its motion from a connecting rod driven by the crank shaft. Single and double-acting cylinders are made for use with these heads, the pump barrel being of seamless brass tubing with a cast bronze attachment at the top and bottom, the upper one threaded for standard wrought pipe connection of a size larger than the cylinder to admit of withdrawing plunger and lower valve. The bottom attachment is threaded for suction pipe or strainer. In the operation of the double-acting pump cylinder, water is discharged on the up stroke through the valve D1, in the top of the pump plunger, while D2 is the discharge on the down stroke; S1 acts as suction valve on the down stroke, and S2 on the up stroke.

Glendora Artesian Well Pumps, built by the Deane Steam Pump Co., have box-form uprights, supporting 5 cranks on a single shaft, the center one directly connected by rod and crosshead to the inside plunger, which is the lowest of the three. On either side of the center crank, and at 120 deg. to it, are 2 cranks similarly connected to a cross yoke carrying a tubular rod attached to the middle plunger. Outside cranks set at 120 deg. to the others are connected to the lower cross yoke, which is secured to the tubular rod carrying the uppermost plunger. Load comes always on the up stroke of each plunger, and this, with the arrangement of cranks, gives a load evenly divided between crank shaft bearings and always downward thrust, the angular thrust being taken by heavy bored crosshead guides.

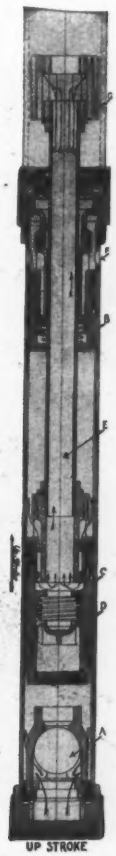
AMERICAN DISPLACEMENT PUMP



DEMING DEEP WELL POWER HEAD AND DOUBLE-ACTING PUMP

Pumps for deep well working, made by the Goulds Mfg. Co., are built in 2 styles, the differential and the single acting. The latter has the frame and base in one piece, and the stroke is adjustable by changing the wrist pins in the driving wheels, shorter stroke being used for forcing to a higher elevation. In the differential type 2 cranks at 180 deg. are employed, the cast-iron differential plungers working through outside packed stuffing boxes with bolted glands. In the double-acting pump cylinder, water is discharged on the up stroke through the valve C, into passage E, and at the same time A acts as a suction valve, admitting water beneath the plunger. On the down stroke water is forced up through the valve D as a discharge valve into passage E, and is drawn in through valve B and ports F to the upper half of the cylinder.

AMERICAN WELL WORKS 2-STROKE TYPE DEEP WELL PUMP



GOULDS DOUBLE-ACTING DEEP WELL PUMP

For the power head made by the Hill Pump Co., an upright casting carries 2 bearings for the gudgeons of the gear wheels and on the rear side 2 similar bearings for the pinion and pulley shaft. A double steel pinion cast in one piece and keyed to the pinion shaft meshes with double gears joined by a wrist pin, bringing gears and gudgeons in alinement. Power is continually applied to both sides of the wrist and the connecting rod carrying load direct eliminates torsion.

In the non-pulsating deep well pump made by the Luitweiler Pumping Engine Co., rotary motion of the

driving shaft is transformed into straight line movement by cams, 2 cams being key seated oppositely on one shaft and transferring the power to sliding yokes through friction rollers. Each cam lifts the load through slightly more than a half revolution, the overlap permitting shifting the load gradually from one cam to the other. Between intervals of overlap the rise of the cam is even, and carries the water load without acceleration. In the illustration rotation is counter clockwise, and the upper cam is just reaching its upper limit, while the lower cam has already started its roller on the upward travel. Two pistons are arranged in one cylinder at any depth below the pump head, driven through balanced sets of rods, one connected to each sliding yoke.

Underwriters' Pumps

Pumps used for fire service are usually constructed according to the specifications of the mutual factory underwriters' board. They are of heavy construction, with large valve area, since they must run at high speeds, with large air chambers on the suction and discharge, a stroke register, a relief valve and cast-iron discharge cone, steam and water pressure gages, sight feed lubricator and oil pump, brass priming pipe, cushion valves which can be controlled to regulate the length of the stroke and quiet action, and are made rust proof by the use of bronze for piston and valve rods, stuffing boxes and rock shaft bearings. Valve levers are made of wrought iron. The pumps are furnished with a capacity plate which shows in black enamel letters, ½ in. high, on a white enamel ground, or in polished letters, ½ in. high, on a black ground, the diameter of cylinders and stroke, capacity in gallons per minute, or in number of 1⅛-in. nozzle streams, full speed in revolutions or double strokes, and the legend, "For fire purposes, never let steam get below 50 lb., nights or Sundays."

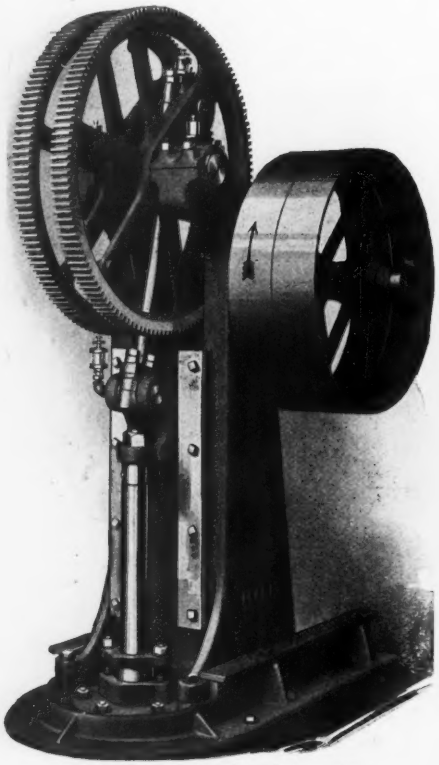
Rotary pumps are frequently used for fire purposes, two types being allowed, one the type A being somewhat smaller and less expensive, and the Type B being recommended. Such pumps must be of the double impeller type with 2 main shafts pumping by means of interlocking cams, and must have cylinders, heads and cams of bronze castings.

The air chamber, if not a part of the discharge casting, should be attached by flange connection at the top of the discharge casting and for the recommended type to be of capacity shown in the table; for the Type A or less expensive to have a capacity of 5 gal. less. It must be tested to 400 lb. pressure and painted inside and out.

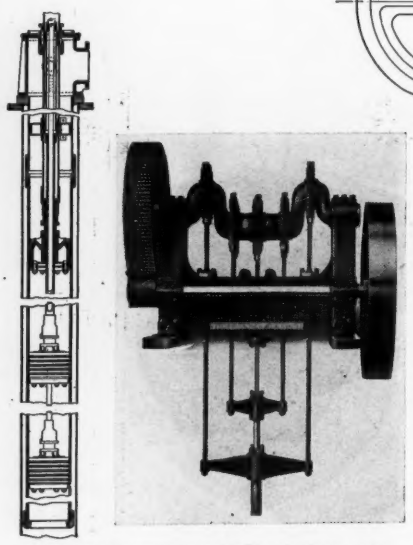
If suction lift is over 15 ft., the diameter of suction pipe must be at least 2 in. above that of the inlet opening, the increase being made by use of a tapered cone, as shown in the illustration. Rotary pumps are to be rated at 250 to 300 r.p.m., and should be able to run at 25 per cent over the rated speed with 100 lb. pressure and deliver 10 per cent above the rated capacity when new.

Hints on Setting and Operating Pumps

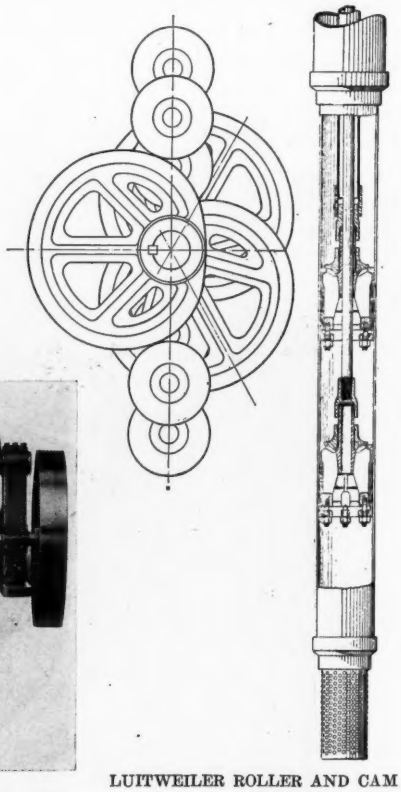
Care should be taken that the suction is arranged in accordance with principles already stated, that all joints are air tight, and that the suction is short and with few bends. If the length is over 15 ft. a foot valve



HILL POWER DEEP WELL HEAD



GLENDORA ARTESIAN WELL HEAD AND PUMP BARREL

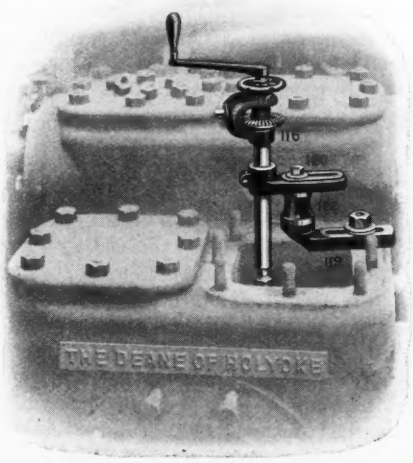


LUITWEILER ROLLER AND CAM MECHANISM AND SECTION OF WORKING BARREL

should be used to keep the suction pipe filled with water. If the pipe is long, use a size diameter larger than that of the pump inlet. A strainer at the end of the suction should be used if there is any possibility of getting dirt into the pump, the area of passages through the strainer being 3 to 5 times the area of the pipe, so that there will be free action in case part of the strainer is clogged. For long suction pipe, the grading should be gradual and continuous towards the supply, not less than 6 in. to 100 ft., and all chance for air pockets carefully avoided.

DIMENSIONS OF RECIPROCATING UNDERWRITERS' PUMPS

Capacity G.P.M.	No.1-1/8 In. Fire Streams	Diam. Cylinders		Stroke	R.P.M.	Steam Press.	Boiler Hp.	Diam. Pipes				Air Chamber		Relief Valve Diam. In.
		Steam In.	Water In.	In.		Lb.		Inlet In.	Outlet In.	Steam In.	Exhaust In.	Neck Diam. In.	Capacity Gal.	
500	2	14	7	12	70	40	100	8	6	3	4	5	15	3
750	3	16	9	12	70	45	115	10	8	3½	4	6	20	3½
1000	4	18	10	12	70	45	150	12	8	4	5	6	25	4
1500	6	20	12	16	60	50	200	14	10	5	6	8	35	5



LEAVITT PUMP VALVE RESEATING MACHINE

Drain cocks should be provided for both suction and discharge piping if there is liability of freezing.

Reciprocating pumps are usually run at a speed which does not require a heavy foundation, but the pump should be securely bolted down on a substantial floor or timber. In case of centrifugal pumps, the speed requires a substantial foundation, best made of concrete with foundation bolts. No piping should be attached to a centrifugal pump until it has been properly erected and the grouting hard and dry, and care should be taken not to spring the pump when attaching piping.

For hot or heavy liquors suction should be arranged so that the liquors come to the pump under pressure.

A hard metallic knock just before the end of the stroke, is usually due to water hammer in the steam end, and can be remedied by opening the drip in the steam cylinder. If it continues, the steam chest should be drained by a drip pipe to carry away the water before it enters the steam cylinder.

The power of boiler feed pumps can be considerably increased by piping the exhaust into the suction pipe if the exhaust steam is not needed for other purposes. In this way the water serves to condense the exhaust steam, and the exhaust steam heats the feed water. This heating cannot, of course, be carried to the point where the temperature of the water interferes with the suction of the pump end.

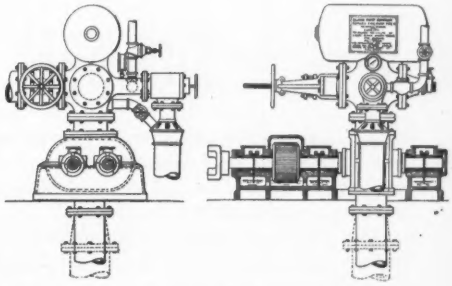
Valves should be examined occasionally to see that they are seating properly and to make sure that foreign substances are not lodged between the valve and seat. If valve seats become scored they should be reseated, a convenient outfit made for this purpose by the Leavitt Machine Co., being shown in the cut herewith. In power pumps particular attention must be paid to the bearings to see that they are kept clean and well lubricated, and metal gearing should be oiled, but on rawhide pinions, use good graphite only. For power pumps it is always well to provide a bypass to the discharge since the speed of the pump cannot be easily regulated, while the discharge may require to be varied.

In starting up a centrifugal pump, do not attempt to run it empty. It must first be filled with water, and air removed from the casing by one of the methods shown in the section under centrifugal pumps.

In operating a vacuum pump, if it is not pulling the proper vacuum, it is not desirable to increase the speed too high, but careful examination should be made for leaks in the valves, joints and packing.

DIMENSIONS OF ROTARY FIRE PUMPS

Capacity G.P.M.	Hp. to Drive	No. of 1-1/8 in. Streams	Inlet and Outlet Diam. In.	Nose Connection Opening In.	Relief Valve Diam. In.	Waste Pipe Diam. In.	Starting Air Valve In.	Air Chamber	
								Neck Diam. In.	Capacity Gal.
500	60	2	6	5	3	5	2	5	15
750	90	3	8	6	3½	6	2½	6	20
1000	120	4	8	7	4	7	2½	6	25
1500	180	6	10	8	5	8	3	8	35



ROTARY UNDERWRITERS' PUMP TYPE B

Condensers

CONDENSERS ARE EMPLOYED to reduce steam consumption of existing prime movers, and increase station capacity without increasing number of steam generating units, where proper feed water is available only at excessive cost, thus allowing water to be re-used with addition of but small amount of makeup and where exhaust steam is not required for heating or manufacturing purposes. Local conditions largely govern the advisability of installing condensing plants, as in many instances the saving of fuel due to the use of condensers is totally offset by the interest on investment, depreciation, taxes, etc., for extra building space, foundations, piping and auxiliaries. Where but one engine or turbine is employed operating under a load factor of 10 per cent or less, it has been found uneconomical to run condensing; where, however, 2 or more engines or turbines are installed, higher economy may be obtained by fitting only a portion of the prime movers with condensing equipment, and employing those thus provided to carry the continuous and heavier loads with the noncondensing units carrying the peak.

TABLE I. POUNDS COOLING WATER REQUIRED PER POUND OF STEAM-SURFACE CONDENSERS

Temp. of Cooling Water, Deg. F.	Temp. of Discharge Water, Deg. F.	Vacuum, Inches Mercury						
		22	24	26	27	28	29	29.5
35	80	22.3	22.5	22.6	22.8	22.9	23.2	23.5
	90	18.3	18.3	18.4	18.5	18.8	19.0	19.2
	100	15.4	15.5	15.6	15.8	15.9	16.1	16.2
	110	13.5	13.6	13.6	13.6	13.7	13.9	14.1
	120	11.8	11.9	12.0	12.0	12.1	12.3	12.4
	130	10.6	10.6	10.7	10.8	10.8	11.0	11.1
	140	9.5	9.6	9.7	9.8	9.8	9.9	10.0
40	80	25.1	25.3	25.5	25.6	25.8	26.1	26.4
	90	20.1	20.2	20.4	20.5	20.6	20.9	21.1
	100	16.7	16.8	17.0	17.1	17.2	17.4	17.6
	110	14.3	14.4	14.5	14.6	14.7	14.9	15.1
	120	12.5	12.6	12.7	12.8	12.9	13.0	13.2
	130	11.1	11.2	11.3	11.4	11.4	11.6	11.7
	140	10.0	10.1	10.2	10.2	10.3	10.4	10.5
50	80	33.5	33.7	34.0	34.2	34.4	34.9	35.2
	90	25.1	25.3	25.5	25.6	25.8	26.1	26.4
	100	20.1	20.2	20.4	20.5	20.6	20.9	21.1
	110	16.7	16.8	17.0	17.1	17.2	17.4	17.6
	120	14.3	14.4	14.5	14.6	14.7	14.9	15.1
	130	12.5	12.6	12.7	12.8	12.9	13.0	13.2
	140	11.1	11.2	11.3	11.4	11.4	11.6	11.7
60	80	50.3	50.6	51.0	51.3	51.7	52.3	52.9
	90	33.5	33.7	34.0	34.2	34.4	34.9	35.2
	100	25.1	25.3	25.5	25.6	25.8	26.1	26.4
	110	20.1	20.2	20.4	20.5	20.6	20.9	21.1
	120	16.7	16.8	17.0	17.1	17.2	17.4	17.6
	130	14.3	14.4	14.5	14.6	14.7	14.9	15.1
	140	12.5	12.6	12.7	12.8	12.9	13.0	13.2
70	80	100.6	101.2	102.1	102.7	103.4	104.7	105.8
	90	50.3	50.6	51.0	51.3	51.7	52.3	52.9
	100	33.5	33.7	34.0	34.2	34.4	34.9	35.2
	110	25.1	25.3	25.5	25.6	25.8	26.1	26.4
	120	20.1	20.2	20.4	20.5	20.6	20.9	21.1
	130	16.7	16.8	17.0	17.1	17.2	17.4	17.6
	140	14.3	14.4	14.5	14.6	14.7	14.9	15.1
80	90	100.6	101.2	102.1	102.7	103.4	104.7	105.8
	100	50.3	50.6	51.0	51.3	51.7	52.3	52.9
	110	33.5	33.7	34.0	34.2	34.4	34.9	35.2
	120	25.1	25.3	25.5	25.6	25.8	26.1	26.4
	130	20.1	20.2	20.4	20.5	20.6	20.9	21.1
	140	16.7	16.8	17.0	17.1	17.2	17.4	17.6
90	100	100.6	101.2	102.1	102.7	103.4	104.7	105.8
	110	50.3	50.6	51.0	51.3	51.7	52.3	52.9
	120	33.5	33.7	34.0	34.2	34.4	34.9	35.2
	130	25.1	25.3	25.5	25.6	25.8	26.1	26.4
	140	20.1	20.2	20.4	20.5	20.6	20.9	21.1

According to types, condensers may be classified as surface, jet, barometric and centrifugal.

Surface Condensers

SURFACE CONDENSERS usually consist of cast-iron or steel cylindrical or rectangular ribbed shells, fitted with nests of brass or composition tubes held in heads near the ends of the shell by expansion or brass ferrules and packing, or by expansion at one end and by the ferrules and packing at the other. A dished head or heads, depending upon the form and size of condenser, are bolted to the end of the shell, and by means of cast-in partitions provide suitable chambers and deflectors for the accommodation of the circulating water. Surface condensers are built for horizontal or vertical installation, and may be arranged for the passage of the cooling water through the tubes with the exhaust steam surrounding them, or as is often done in water works practice with steam passing through the tubes and cooling water on the outside.

A baffle opposite the exhaust steam inlet protects the upper row of tubes from water brought from the engine or turbine, while drain plates are frequently provided to intercept the condensed steam flowing over this baffle and deflect it to the sides and bottom of the condenser chamber so as to keep the tubes dry.

In single-flow condensers the cooling water enters at one end of the shell, passes through the tubes into the opposite head, and out. Exhaust steam fills the shell, is condensed by contact with the comparatively cool tubes and drops to the bottom of the shell, whence it is removed by an air pump.

In double-flow surface condensers, the cooling water, instead of making but one passage through the shell, is caused to flow first through an upper set of tubes in one direction, by means of a partition dividing the head, into which the cooling water is introduced, into 2 compartments. By means of additional properly located partitions in each head a multiflow arrangement is obtained.

Wherever possible, all modern surface condensers are so installed and connected that the steam to be condensed enters at or near the top of the shell and in condensing flows downward, while the cooling water is introduced at the bottom and caused to leave through an outlet on top, creating a counterflow of the 2 fluids.

Some forms of these condensers are provided with a spiral partition or baffle, which causes the steam to follow a spiral path and to reduce the condensing surface area in about the same proportion as the decrease in the quantity of steam to be condensed, the interior of this spiral baffle forming an air cooler to cool the air and remove any water that may remain therein.

Jet Condensers

IN JET CONDENSERS generally built of cast iron, pear-shaped or rectangular in form, steam is brought into intimate and direct contact with the cooling water, the combined mass falling to the bottom of the condensing chamber, whence it is removed by a pump provided for the purpose, or otherwise as outlined below. In the majority of makes, exhaust steam is introduced at the side and near the top of the shell, and the cooling water enters at the top and is controlled by some form of spray valve, which not only regulates the quantity of water flowing, but distributes it in such a manner as to bring about proper and intimate mixture of steam and water.

Barometric Condensers

THESE, which are a form of the jet condenser, depend upon the use of a barometric column exclusively for the removal of the condensate, cooling water and some times the entrained air and other noncondensible vapors, although the latter are more generally removed by dry-vacuum pumps. In some types of barometric condensers an auxiliary air drain running parallel to the tail pipe is employed in connection with the pump.

Barometric condensers essentially consist of cast-iron vessels or heads mounted upon a tail pipe at least 34 ft. above the overflow of the hot well, and are provided with the necessary exhaust steam, injection water, tail pipe, overflow and dry-vacuum-pump suction connections. The relative locations of injection water and exhaust steam inlets vary considerably, some builders placing the former above the latter, in which case part of the steam is caused to rise in order to meet the cooling water, and the condenser is, therefore, known as of the counter-current type; in others, the steam is introduced above the cooling water inlet, either through an opening at the side of the condenser or directly through the top, thus causing both steam and water to flow downward at all times, and are referred to as parallel-flow barometric condensers.

Centrifugal Condensers

These, while practically simple jet condensers, derive their name from the wet-vacuum pump used in connection with them, and which may be of the ordinary centrifugal or some special type.

TABLE II. POUNDS INJECTION WATER REQUIRED PER POUND OF STEAM—JET CONDENSERS

Hot Well Temp. Deg. F.	Initial Temp. Injection Water Deg. F.	Vacuum, Inches Mercury						
		22	24	26	27	28	29	29.5
120	35	13.2	13.1	13.0	11.9	11.9	11.8	11.6
	40	12.9	12.8	12.7	12.7	12.6	12.5	12.4
	50	14.8	14.7	14.6	14.5	14.4	14.3	14.1
	60	17.3	17.1	17.0	16.9	16.8	16.7	16.5
	70	20.7	20.6	20.4	20.3	20.2	20.1	19.8
	80	25.9	25.6	25.5	25.4	25.3	25.0	24.8
	90	34.6	34.3	34.0	33.9	33.7	33.4	33.1
	100	51.8	51.5	51.1	50.9	50.6	50.1	49.6
	110	103.5	103.0	102.2	101.8	101.2	100.2	99.3
110	35	13.9	13.8	13.7	13.7	13.6	13.5	13.2
	40	14.9	14.8	14.7	14.6	14.6	14.4	14.3
	50	17.4	17.3	17.2	17.1	17.0	16.8	16.7
	60	20.9	20.8	20.6	20.5	20.4	20.2	20.0
	70	26.1	26.0	25.8	25.7	25.5	25.3	25.0
	80	34.8	34.6	34.4	34.2	34.1	33.7	33.4
	90	52.2	52.0	51.6	51.4	51.1	50.6	50.1
	100	104.5	104.0	103.2	102.8	102.3	101.2	100.3
100	35	16.2	16.1	16.0	15.9	15.8	15.7	15.5
	40	17.5	17.5	17.3	17.3	17.2	17.0	16.8
	50	21.1	21.0	20.8	20.7	20.6	20.4	20.2
	60	26.3	26.2	26.0	25.9	25.8	25.5	25.3
	70	35.1	35.0	34.7	34.6	34.4	34.0	33.7
	80	52.7	52.5	52.1	51.9	51.6	51.1	50.6
	90	105.5	105.0	104.2	103.8	103.3	102.2	101.3
90	35	19.3	19.2	19.0	19.0	18.9	18.7	18.6
	40	21.3	21.2	21.0	20.9	20.8	20.6	20.4
	50	26.6	26.5	26.3	26.2	26.0	25.8	25.5
	60	35.5	35.3	35.0	34.9	34.7	34.4	34.1
	70	53.2	53.0	52.6	52.4	52.1	51.6	51.1
	80	106.5	106.0	105.2	104.8	104.3	103.2	102.3
80	35	23.9	23.7	23.6	23.5	23.4	23.1	22.9
	40	26.8	26.7	26.5	26.4	26.3	26.0	25.7
	50	35.8	35.6	35.4	35.2	35.1	34.7	34.4
	60	53.7	53.5	53.1	52.9	52.6	52.1	51.6
	70	107.5	107.0	106.2	105.8	105.3	104.2	103.3
70	35	31.0	30.8	30.6	30.5	30.3	30.0	29.8
	40	36.1	36.0	35.7	35.6	35.4	35.0	34.7
	50	54.2	54.0	53.6	53.4	53.1	52.6	52.1
	60	108.5	108.0	107.2	106.8	106.3	105.2	104.3

On account of the inefficient absorption of heat in practical installations, it is necessary to add from 5 to 20 per cent to the theoretical weight of the cooling water as determined by the above methods in order to obtain approximate values of the total quantity of cooling water required in any specific case.

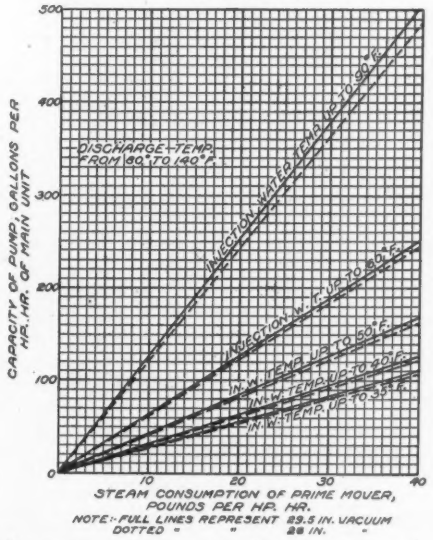
Handling Water and Air

Due to the rise in temperature of the injection or cooling water and the condensation of the steam, it is necessary that this water, together with the air drawn in by leakage or carried in by the steam and water, be continually removed. This is accomplished by a combined air and condensate, or wet-vacuum pump, or by separate condensate and dry-vacuum pumps, depending upon the type and size of condenser.

In the ejector condenser, in which the cooling water is drawn in continuously by the vacuum formed, and sufficient velocity is imparted to the jet to discharge the combined mass of condensed steam, cooling water and air against the pressure of the atmosphere, no pump is required. Ordinary jet condensers are generally directly connected to the suction of the wet-vacuum pump, which may be of the reciprocating, centrifugal or turbine type, and used to remove the cooling water condensate and air and other noncondensible gases.

The barometric condenser, while requiring no pump for the removal of the condensate and cooling water, does not like the ejector type depend upon the velocity of the incoming steam to accomplish this, but is mounted 34 ft. or more above the hot-well overflow and provided with a tail pipe in which the water rises to such a height that due to its weight it will flow out against the pressure of the atmosphere.

THEORETICAL RELATION OF CIRCULATING PUMP CAPACITY TO STEAM CONSUMPTION OF MAIN UNIT—FOR SURFACE CONDENSERS



While some makes of the barometric condenser require no air pump, others are provided with a small pump for removing the air not drawn out by the descending column of water.

Gain from Condensers

The heat efficiency of a steam engine or turbine is equal to the difference between the temperature of the steam admitted and the temperature of the steam rejected, divided by the temperature of the steam admitted. And as the pressure varies directly as the temperature, reduction in back pressure and resulting increase in mean effective pressure due to the use of a condenser will, with fixed initial pressure, increase the heat efficiency of the machine.

Knowing the steam pressure at the throttle of the engine and the per cent cutoff, the theoretical per cent gain in power due to the use of a condenser may readily be determined from the curves shown herewith.

This increase in available horsepower is, however, always more apparent than real, as the condenser auxiliaries in practice use the equivalent of from 1 to 15 per cent of the main engine or turbine steam, depending upon the size of the plant, type and size of prime

movers, size and nature of load, type of condenser and the character and number of auxiliaries and the method of driving employed.

Details and Proportions

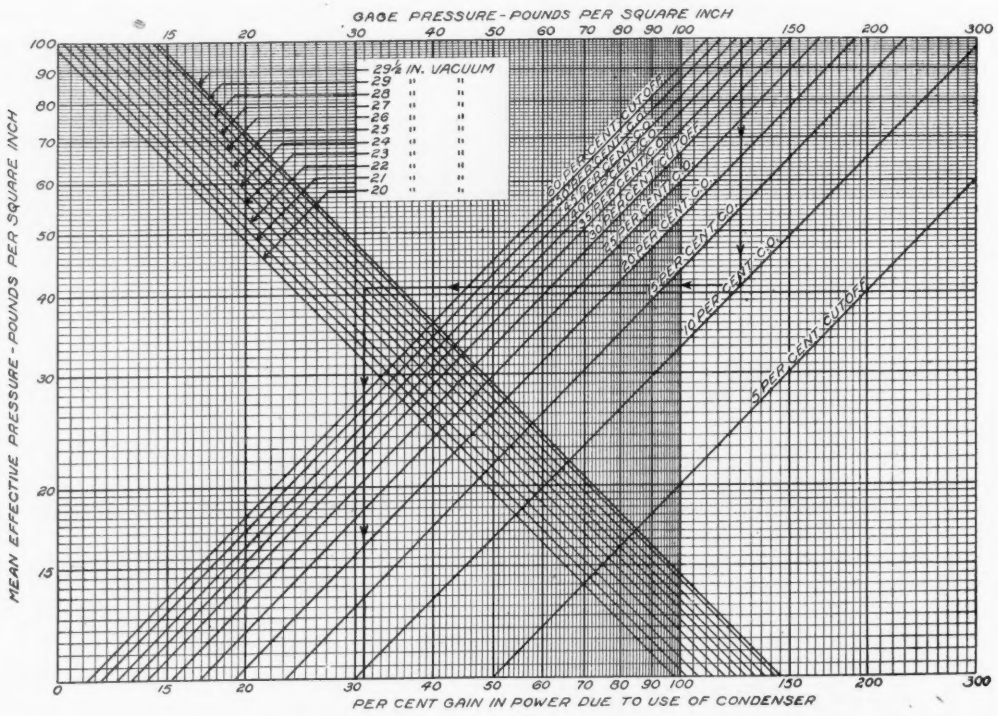
Practically the cooling surface of any surface condenser is calculated as tube surface only. The number of square feet of cooling surface required depends on 3 factors: Weight of steam required to be condensed per hour; total heat above 32 deg. F. of the exhaust steam at condenser pressure minus the heat in the condensate at the final temperature of the condensed steam; and B.t.u. transmitted per hour per square foot of cooling surface for each degree difference between the temperature of the condensed steam plus 32). Hence, to find the cooling surface in square feet, divide (weight of condensed steam per hour times the difference between total heat of the exhaust steam at condenser pressure and the final temperature of the condensed steam plus 32) by (the coefficient of heat transmission times the difference between exhaust steam temperature at condenser pressure and the mean circulating water temperature.*

On account of its better heat transmission, condenser tubes are generally made of brass or other composition containing a greater or less percentage of copper and with diameters ranging from ½ to 1 in. These sizes appear to represent established practice, as smaller tubes would introduce excessive resistance to the flow of the water and larger ones, in order to be of sufficient strength to carry their own weight and that of the contained water, would require a thickness resulting in reduction of heat transmision and efficiency. Sometimes, for protection against corrosion, the tubes are tinned on the inside or on both sides.

The shell must be of such size as to provide for ready inspection, cleaning and repairs with heads of sufficient volume to care for a continuous and unrestricted flow of cooling water. The shell is designed and the tubes arranged so that the upper portion has a volume equal to approximately from ¼ to ⅓ of the shell unoccupied; the steam is compelled to pass between al of the tubes and provision is made in the lower compartment for cooling the air and water before discharge.

While there are no fixed rules or formulas governing the size of jet condenser chambers required for various services, they must not be so small as to result in continual flooding and its detrimental results to the engine

GAIN IN POWER DUE TO USE OF CONDENSER


GAGE PRESSURE - POUNDS PER SQUARE INCH
MEAN EFFECTIVE PRESSURE - POUNDS PER SQUARE INCH
PER CENT GAIN IN POWER DUE TO USE OF CONDENSER
29½ IN. VACUUM
29 " "
28 " "
27 " "
26 " "
25 " "
24 " "
23 " "
22 " "
21 " "
20 " "
5 PER CENT CUTOFF
10 PER CENT CUTOFF
15 PER CENT CUTOFF
20 PER CENT CUTOFF
25 PER CENT CUTOFF
30 PER CENT CUTOFF
40 PER CENT CUTOFF
50 PER CENT CUTOFF

temperature of the exhaust steam at condenser pressure and the mean temperature of the circulating water. This last expression is known as the coefficient of heat transmission. Since the heat given up by the steam is equal to that absorbed by the cooling water, the product of the number of square feet of cooling surface times the coefficient of heat transmission is equal to the weight of condensed steam per hour times (the total heat of the exhaust steam at condenser pressure less the final tem-

*Let S be the cooling surface in square feet; Hs the total heat of the exhaust steam at condenser pressure, and Ts its temperature; T_1 the initial and T_2 the final temperature of circulating water, T_0 the final temperature of condensed steam; all in deg. F.; U, the coefficient of heat transmission; d, the difference in mean temperatures, which according to Whitham is:

$$d = Ts - \frac{T_1 + T_2}{2}$$

and W the weight of condenser steam per hour.

We have, $S\,U\,d = W\,[Hs - (T_0 - 32)]$

$$S = \frac{W\,[Hs - (T_0 - 32)\cdot]}{U\,d}$$

With circulating water velocities of from 25 to 50 ft. a min., the value of U with plain brass tubes is 250, and for corrugated tubes 300; when the velocities vary from 75 to 150 ft. per min., the above values of U may be increased by 50 per cent.—Steam Power Plant Engineering, Gebhardt.

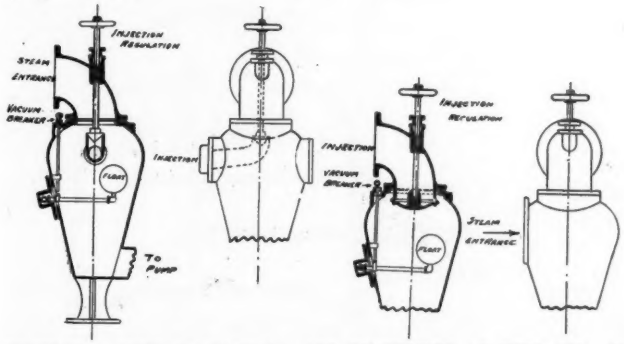
or turbine, nor so large as to require too great a length of time for the air pump to create a vacuum. From measurements of commercial condensers and opinions expressed by various authorities, it is found that the volume of this chamber ordinarily ranges from ¼ to ¾ that of the engine cylinder served.

Two of the most important precautions required in the design of jet condensers are to place the exhaust steam inlet some distance above the point of injection water discharge, so as to avoid the possibility of flooding the engine or turbine, and to provide such shape that the condensate and injection water will readily drain towards the outlet.

The required area of the steam inlet is governed by the diameter of the pipe* required to carry the steam to the condenser, found by multiplying 0.175 by (the square root of the quotient from dividing the weight of steam flowing in pounds per minute, by the density of the steam in pounds per cubic foot).

Having determined the required quantity of cooling water by the tables previously given, the size of the water inlet is governed by the size of pipe required to conduct the water from the source of supply to the condenser at a reasonable loss from friction.

Injection pipe diameters are generally based on a water velocity ranging from 400 to 600 ft. per min., and discharge pipe diameters on velocities of from 200 to 400 ft. per min.



SECTIONAL VIEW OF BUFFALO JET CONDENSER AS USED ON PUMPS 7 BY 10 BY 12 IN. AND SMALLER

SECTIONAL VIEW OF BUFFALO JET CONDENSER AS USED ON PUMPS 8 BY 12 BY 14 IN. AND LARGER

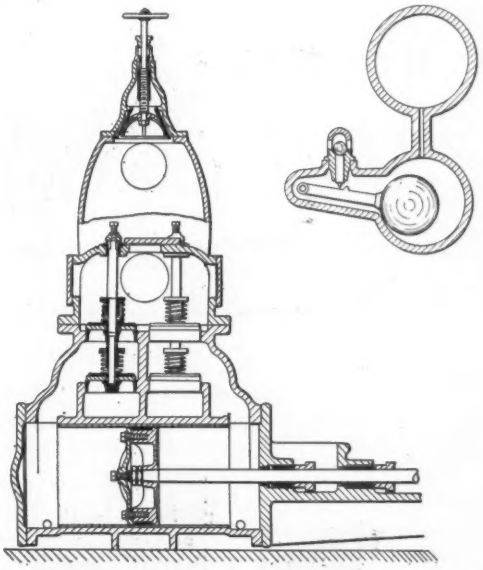
Except for somewhat greater refinement and the method employed in handling the condensate and injection water, barometric condensers are much like the ordinary jet condenser and therefore all that has been said relative to the size of condensing chamber and exhaust steam and injection water inlets in jet condensers will equally well apply to barometric condensers.

Vacuum Breakers

As its name implies, the function of a vacuum breaker, which is placed in the condenser proper, is to break or destroy the vacuum in a condenser and protect the engine or turbine from possible flooding should the condenser fill with water from any cause. This should not be confused with the atmospheric relief valve, which is placed in the exhaust line between the engine or turbine and condenser to provide a means of escape of the steam with minimum back pressure, when the condenser becomes inoperative.

With slight modifications, the ordinary vacuum breaker consists of a ball float, placed either in the condenser proper or in an adjoining and communicating compartment, and which upon flooding of the condenser shell will operate a valve either located at the side or top of the shell and allow a rush of air into the condenser chamber or the adjacent exhaust steam line. These valves are operated directly by float or through the medium of steam actuated piston, controlled by the float and lever.

Other types of vacuum breakers not used as generally, however, consist of electrically or mechanically operated valves placed in the line between engine and condenser or directly on the condenser and used in connection with an engine stop system. While employed primarily for the purpose of preventing overspeeding of the engine, under certain conditions these act as effectively as the other types.



SECTIONAL VIEW OF CAMERON JET CONDENSER, WATER END OF PUMP AND VACUUM BREAKER

Choice of Condenser

This depends almost entirely upon local operating conditions, and the nature and quantity of boiler feed and cooling water available. Where high vacuums are desired and where plentiful and cheap cooling water suitable also for boiler feed purposes is available, some form of jet condenser may be used; the siphon or barometric types being undoubtedly the best suited and least expensive where the question of sufficient overhead room need not be considered. When the cooling water is exceedingly dirty, the siphon will in turn prove preferable to the barometric.

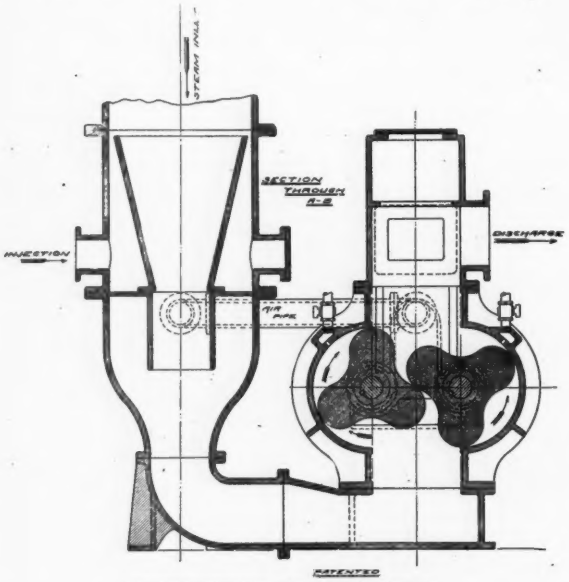
Where a high vacuum is desired in connection with an engine of the reciprocating type, barometric condensers in connection with dry vacuum pumps are generally employed, while steam turbines operating against exceptionally high vacuums generally exhaust into sur-

*The weight of steam flowing in pounds per minute, is equal to the maximum steam consumption of the engines or turbines used in connection with the condenser. The value of density is obtained from a steam table, for the average pressure to be carried in the condenser.

face condensers, which may in general be recommended wherever the cooling water is not fit for boiler feed and where no suitable and cheap supply of pure boiler feed is available.

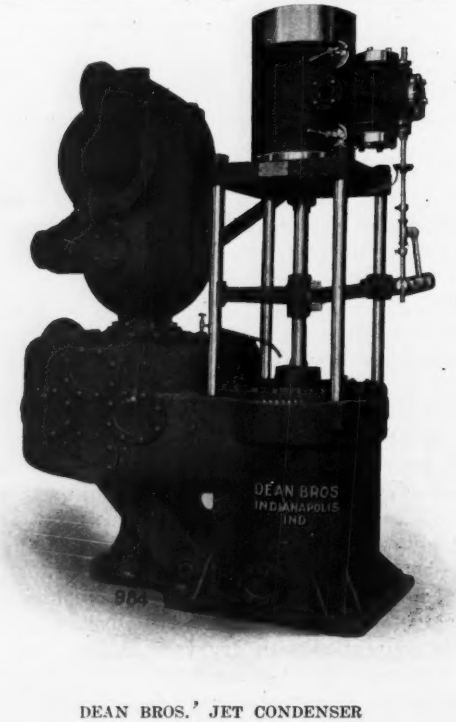
Buffalo Independent Jet Condensers

Two general types of jet condensers are built by the Buffalo Steam Pump Co., which, though similar in external appearances, differ in the method of introducing the steam and injection water. In one type, that



CONNERSVILLE JET CONDENSER

built for use with air pumps of 7 by 10 by 12 in., and smaller, the steam is brought into the condenser through an elbow bolted to the top of the pear-shaped body.

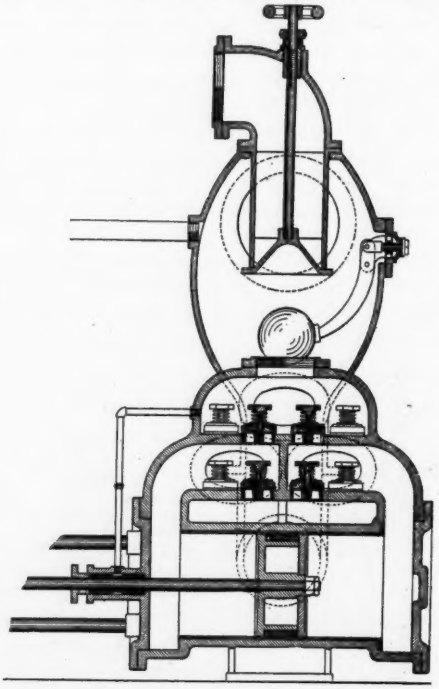


DEAN BROS.' JET CONDENSER

Injection water is introduced through a pipe entering near the top of the body and terminating in a spray head, the opening of which may be varied by means of a hand wheel connected to a stem passing through the top.

Upon entering the condensing chamber, the steam is brought into direct and intimate contact with the fine spray of water issuing from the spray head, when due to the intermingling of the steam and water, the former is condensed and together with the injection water, air and noncondensable vapor, is drawn out of the bottom of the chamber by the air pump.

In the larger sizes, those used with pumps of 8 by 12 by 14 in. and above, the injection water enters through



SECTIONAL VIEW, NATIONAL INDEPENDENT AIR PUMP AND JET CONDENSER

the elbow above and is divided into a fine rain by a spray head at the top of the condensing chamber controlled in the same way as in the smaller type. The incoming steam, tending to rise, meets the falling spray of cold water and is at once condensed, and as with the other, falls to the bottom of the chamber together with the injection water, air and other noncondensable gases, from where it is removed by a pump provided for the purpose.

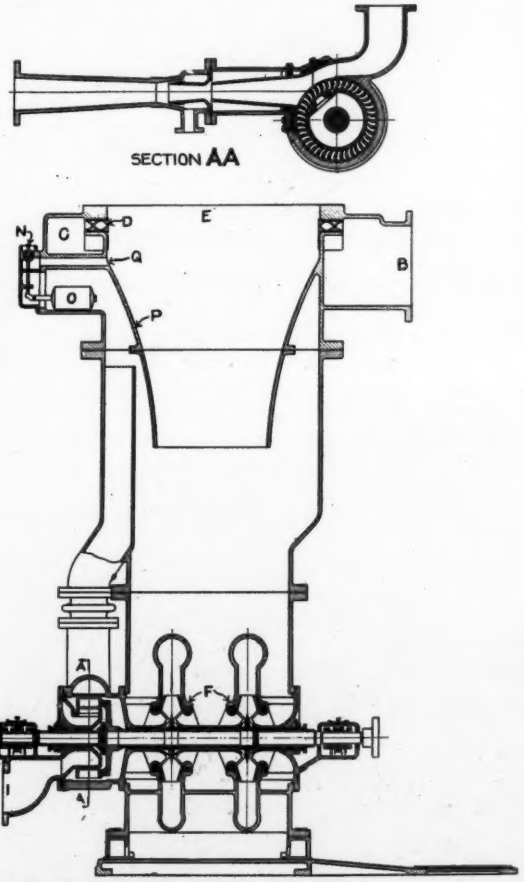
To protect the engines and turbines operated in connection with these condensers from flooding, a vacuum breaker located at the top of the condensing chamber is provided. This is operated by a ball float adjusted to break the vacuum at any predetermined level the water in the condensing chamber may reach.

Cameron Jet Condensers

These condensers, manufactured by The A. S. Cameron Steam Pump Works, are generally furnished direct connected to Cameron single-cylinder air pumps, the steam end of which is described elsewhere in this issue. The vacuum end of the air pump is provided with a

water seal cast integral with the frame, and is fitted with 2 packing glands, as shown in the sectional view. Both suction and discharge valve decks are placed above the cylinder and are equipped with rubber valves and composition valve seats, springs and guards; the valves are held in place by valve stems, each passing through a suction and a discharge valve and secured by lock nuts on top of the valve chest and accessible from the exterior. The cylinder is lined with composition metal.

Excepting for the injection water inlet and control valve, which is bolted to the top thereof, the condenser proper consists of a single pear-shaped casting bolted to an elbow joining the condenser and air pump. Exhaust steam is introduced through an opening near the top of the shell where it is brought into intimate contact with the incoming injection water which is controlled by a valve of such construction that by a few turns of the handle any impediment may be swept away by a larger stream of water.



CROSS SECTION OF WESTINGHOUSE-LEBLANC LOW LEVEL JET CONDENSER AND WESTINGHOUSE-LEBLANC AIR PUMP

A vacuum breaker consisting of a ball float operating a small ball valve which allows the introduction of air into the condensing chamber in the event of any possible flooding, is located directly below the steam inlet.

Connersville Jet Condenser

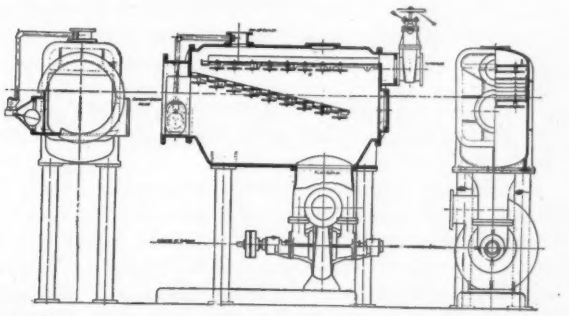
In the Connersville jet condenser, made by The Connersville Blower Co., the condensing water enters a reservoir where rocks or other heavy substances are deposited. From this reservoir, it flows through an annular opening into the condenser chamber and down the sides of the funnel.

Steam coming from the engine or turbine, enters the top, passes into the mouth of the funnel and comes in contact on all sides with water-covered and water-jacketed surfaces. The water rolls down the sides of the funnel and is thoroughly exposed to the impinging steam, the kinetic energy of which is imparted to the water and causes it to form a natural closure of the throat after the water leaves the sides of the funnel, thus trapping and carrying the air with it to the lower chamber.

An air chamber is formed in the lower part of the condenser, the upper and outside walls of which are kept cool by contact with the cooling water above. The mixed air and vapors rise to these cool surfaces where the vapors are condensed and the remaining air cooled before going to the air pump, which is of the Connersville Cycloidal 3-lobe type, serving as a combined water and air pump.

Dean Bros.' Jet Condenser

The accompanying illustration shows a Dean Bros.' vertical air pump and jet condenser, manufactured at the Dean Bros. Steam Pump Works. All the valves are accessible without disturbing any part of



SECTIONAL VIEW OF TYPICAL WHEELER RECTANGULAR JET CONDENSER

pump. Being double-acting, it takes up but little space

The condensing chamber is arranged with a series of cyclone plates and flanges which thoroughly mix the injection water with the incoming steam, introduced through a large opening in the shell at one side and near the top.

National Jet Condensers

The body of these condensers, made by The National Steam Pump Co., consists of the familiar pear-shaped casting to the top of which is bolted an injection water elbow and regulating valve as illustrated in section herewith. Injection water enters the inlet elbow, passes down to a point at about the center of the condensing chamber where it is sprayed by the regulating valve, in which finely divided state it intermingles with and condenses the exhaust steam brought in through an opening near the top of the shell.

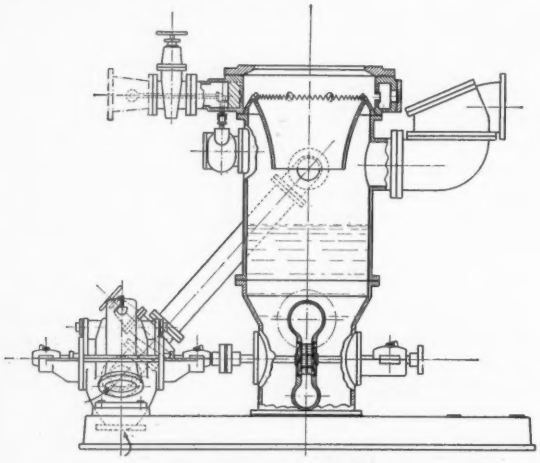
Westinghouse-Leblanc Jet Condensers

There are 3 types of Westinghouse-Leblanc jet condensers, the low level, barometric and ejector.

In the low-level jet condenser shown in the accompanying figure, the condensing water is drawn through

inlet B by virtue of the vacuum in the condenser, passes around the entire periphery of the condenser head, through chamber C, and enters the steam space through helical nozzles D, which are symmetrically distributed around the periphery. The nozzles impart a rotary motion to the water, breaking it up into a fine spray, intimately and thoroughly mixing it with the steam, which enters the condenser through opening E.

The mixture of condensed steam and water falls to the bottom of the condenser and is discharged by the double-suction centrifugal pump F.



C. H. WHEELER JET CONDENSER

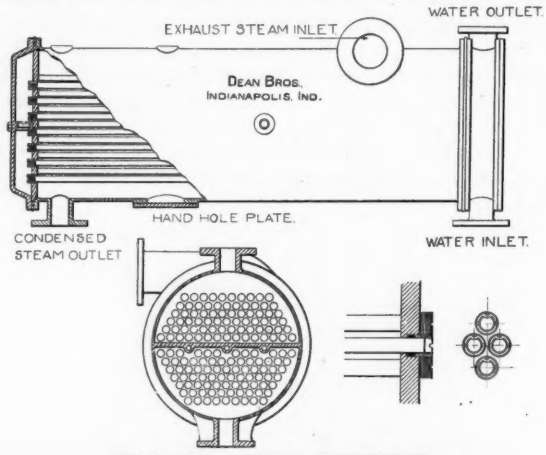
While the air and water pumps are mounted on the same shaft they, with their inlet and discharge openings, are entirely separate.

Accidental stopping of the pumps might result in trouble, as the condensing water would continue to enter the condenser, owing to the vacuum, and might rise to such a point as to cause injury to the turbine. To prevent this, a simple form of vacuum breaker is provided. Should the water in the condenser rise to float O, water sealed valve N is opened, admitting air through passage Q to the condenser, impairing the vacuum and hence stopping the inflow of condensing water at B.

The barometric condenser is similar to the low level jet, the only material difference being that the barometric condenser does not require a pump for discharging the condensed steam and water. It may be used where its location is at least 40 ft. above the level of the discharge water, the condensed steam and water leaving the condenser through the tail pipe by virtue of the static head.

Wheeler High-Vacuum Jet Condenser

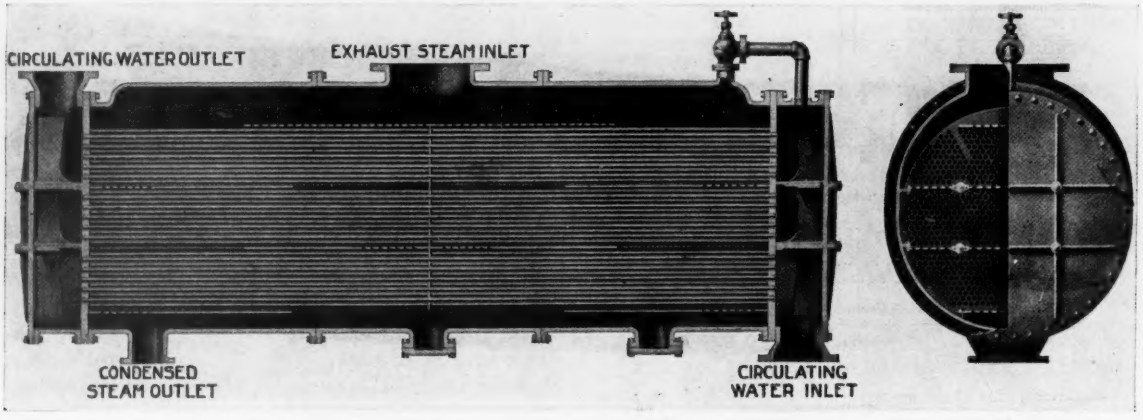
The general construction of this current jet condenser may be readily understood by referring to the accompanying figure. Circulating water entering near the



DEAN BROS. SURFACE CONDENSER

top flows over an upper tray, is broken up by distributors into a fine spray and falls to the lower tray, from which it is re-distributed, thence dropping to the bottom of the condenser. Steam entering at the right, comes into contact with the water (already partially heated) falling from the lower tray and in its progress through the condenser also comes in contact with the comparatively cold water falling from the upper tray. The sectional area of the path of the steam diminishes progressively and is thereby said to eliminate the possibility of any air pockets impairing the vacuum.

After having been cooled by the water in the upper tray, the air and incondensable vapors are removed by the air pump through a proper opening in the top of the shell.

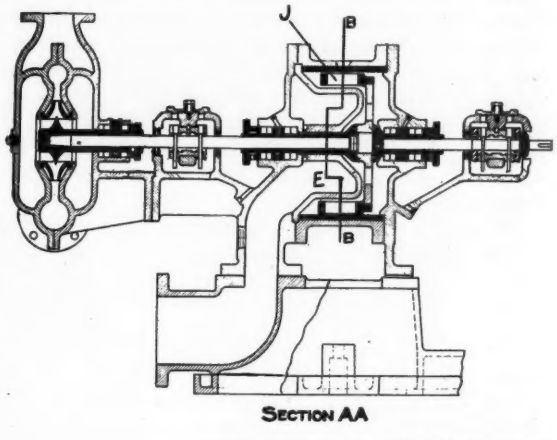


SECTIONAL VIEW OF EYNON-EVANS SURFACE CONDENSER

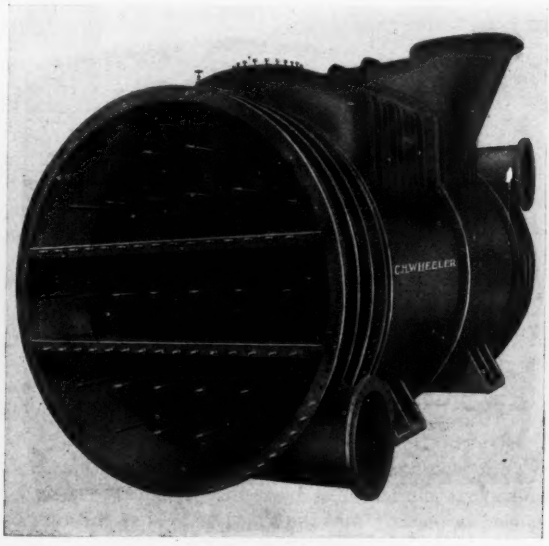
Wheeler high vacuum jet condensers are built by the Wheeler Condenser & Engineering Co.

C. H. Wheeler Jet Condenser

As shown in the accompanying illustration, this condenser consists of a cylindrical cast-iron body, the top section of which is provided with a belt for entering injection water and suitable bronze bushed openings to permit the injection water to impinge against a sloping weir having a serrated edge, which finely divides the injection water so as to bring about an intimate mixture with the exhaust steam entering from above. Below the weir is a tapering entrainment and mixing cone, and below the injection water belt, but on opposite sides of the shell are the vacuum breaker and the atmospheric relief valve connection.



CROSS SECTION OF WESTINGHOUSE-LE BLANC AIR AND CONDENSATE PUMP



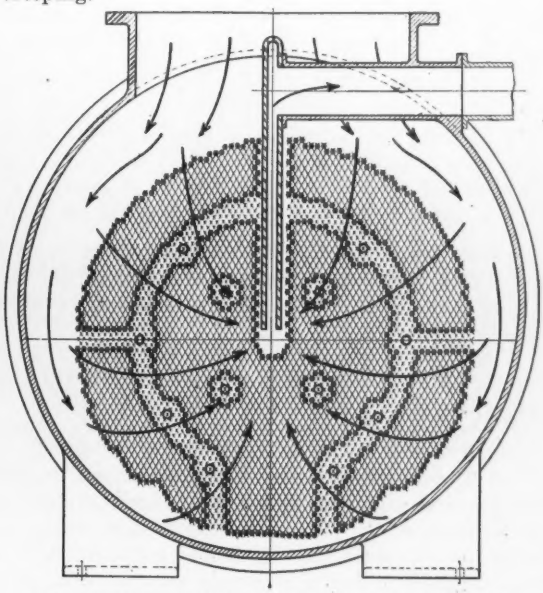
C. H. WHEELER SURFACE CONDENSER FOR 7500 KW. TURBINES, SHOWING STAY BOLTS AND STEAM LANES; 3 PASS DESIGN

The base of the condenser contains a special type high speed submerged centrifugal water removal pump, the casing of which is of cast iron, the impellers of hard bronze and the shaft of alloy steel with heavy bronze sleeve coverings where exposed to the water.

C. H. Wheeler jet condensers are built by the C. H. Wheeler Mfg. Co.

Dean Surface Condensers

Dean Bros.' surface condensers employ shells providing the necessary openings for exhaust steam and water connections, but of such construction as to avoid all air and water pockets. The tubes are of brass, tinned inside and outside, and tube heads are rolled bronze. Tubes are packed at each end with suitable packing, secured with brass screwed ferrules. Baffle plates are arranged for distributing the steam and protecting the tubes at the openings, while transverse plates are employed to diffuse the steam over the tubes. To prevent sagging the tubes are supported at their centers, and stop lugs in ferrules are provided to prevent them from "creeping."



CROSS SECTION SHOWING ARRANGEMENT OF TUBES, WESTINGHOUSE-LE BLANC SURFACE CONDENSER

These condensers, which are constructed in the round or square form, and in sizes having from 80 to 7000 sq. ft. of tube area, are applicable either to direct mounting over combined air and circulating pumps, or may be installed separately.

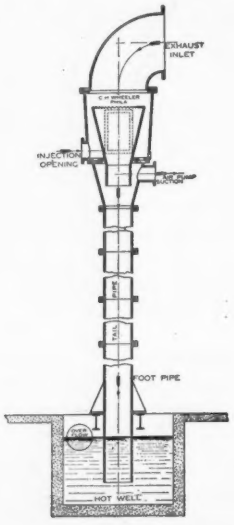
Handholes, ample in size and number, allow ready access to the interior of the condenser for the purpose of cleaning, inspection or repairs.

Dean Bros.' surface condensers are built at the Dean Bros. Steam Pump Works.

Eynon-Evans Surface Condensers

A distinctive feature of the Eynon-Evans surface condensers built by The Eynon-Evans Manufacturing Co., and shown in section herewith, is the design of the body, which is oval in shape, thus allowing the steam to travel more easily towards the condensing tubes.

Steam entering at the top is prevented from coming in direct contact with the tubes by a large perforated deflector, which causes a large portion of it to pass toward the ends of the shell and thereby come in contact with practically all of the available tube surface. A second plate, partially perforated and partially solid, directs the steam again toward the center, while a third plate near the bottom has the same effect as the top one.



C. H. WHEELER BAROMETRIC CONDENSER

Two short plates partly solid and partly perforated are placed directly above the condensed steam outlets at the bottom of the shell. All tubes are held in place at both ends by packed ferrules.

These condensers are built in sizes having from 300 to 3200 sq. ft. of condensing surface and are fitted with brass tubes and iron or brass tube heads.

Westinghouse-Leblanc Surface Condensers

In the smaller sizes of these condensers, the shell and the nest of tubes are concentric and the pitch and arrangement of the tubes such that the pressure drop of the steam in passing from one side to the other is said to be negligible. In the larger sizes, however, due to the distance the steam is required to travel, the nest of tubes is placed eccentric to the shell so that steam enters around the whole periphery. The air offtake consists of 2 parallel plates extending the entire length of the condenser.

One of the distinctive features of this condenser is the method employed for the removal of the air, accomplished by the use of a Westinghouse Le Blanc Air Pump, sectional views of which are shown herewith.

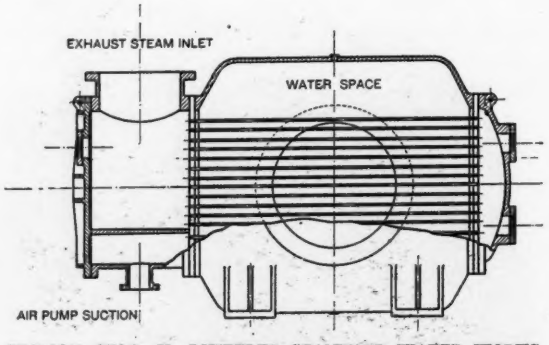
Air from the condenser enters the pump through pipe C. To start the pump, high pressure steam is turned into connection D and as the cone opposite opening D forms the annular nozzle of a steam ejector, a vacuum is created in the body of the pump, and due to which chamber E being connected to a source of water supply is immediately filled. The water then flows through distributing nozzle F and is projected in layers through the combining passage G into the diffuser H. Between the successive layers of water, layers of air are imprisoned. These layers of water, on account of the high peripheral speed of the turbine wheel which throws them off, have a velocity sufficient to enable them to overcome the pressure of the atmosphere and force their way out of the pump. The layers of water act like a succession of water pistons with large volumes of air between them.

Westinghouse-Leblanc surface condensers are built by the Westinghouse Machine Co.

C. H. Wheeler Surface Condensers

These are built with top, side or bottom exhaust steam outlets, and for either "wet" or "dry" operation, as conditions demand. The partitions in the water ends of medium and large size units, dividing the flow of the circulating water in 2 or more passes through the tubes, are provided with stay bolts through the end covers to strengthen the tube plates against atmospheric and water pressure.

All tubes are supported by one or more support plates, depending upon the size of the condenser, and are held in place at both ends by brass ferrules and packing.



SECTION OF C. H. WHEELER STANDARD WATER WORKS SURFACE CONDENSER

For water works and pumping stations, another form of special condenser is built in which case the water is caused to pass around the tubes instead of through them.

Opposite the exhaust inlet openings on all condensers for reciprocating engines, baffle plates are used to prevent the exhaust steam from impinging on the upper rows of tubes. Condensers intended primarily for wet systems and provided with side inlets for the exhaust steam are equipped with deflector baffles to insure active operation of all tubes.

These various types of surface condensers are manufactured by the C. H. Wheeler Manufacturing Co.

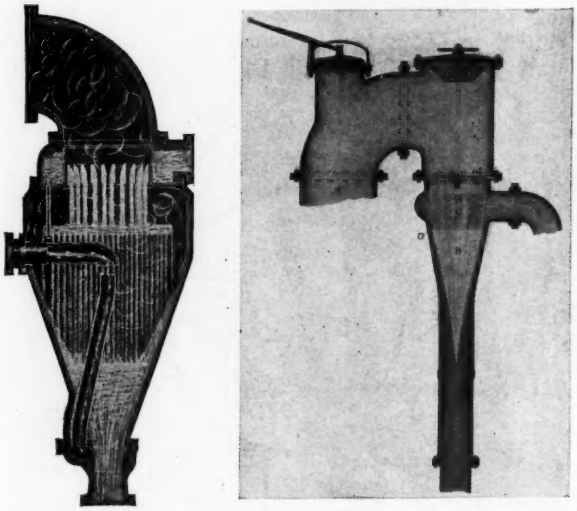
C. H. Wheeler Barometric Condenser

This condenser is of the parallel flow design with weir distribution and tapered distribution cone, utilizing the velocity energy of the incoming steam to carry the air to the air pump suction, and giving a maximum air density at this point.

No tapered entrainment throat in the tail pipe is used, this being kept full diameter for the entire length. The manufacturers, the C. H. Wheeler Co., claim this feature is particularly suitable for the water containing foreign matter in solution, inasmuch as there are no nozzle ports or contracted passages to become clogged.

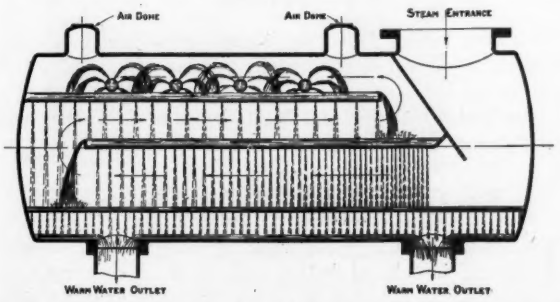
Wheeler Barometric Condenser

As shown in the sectional view, the Wheeler Barometric Ejector Condenser, built by the Wheeler Condenser & Engineering Co., consists of a pear-shaped bell with a large opening at the top to admit the exhaust



SECTIONAL VIEW WHEELER BAROMETRIC EJECTOR CONDENSER

PHANTOM VIEW OF BULKLEY BAROMETRIC CONDENSER



SECTIONAL VIEW GENERAL CONDENSER COUNTER-CURRENT RAIN TYPE CONDENSER

steam, and a second opening at the side for cooling water. At the bottom, connection is made to the barometric column which discharges the water to the atmosphere without the necessity of a tail pump.

Water entering at one side near the top is distributed in an annular reservoir with vertical slots in its inner wall, through which the water falls in a large number of small streams in the direct path of the exhaust steam and into a tray immediately beneath. From here it is redistributed so as to pass through small openings in this tray, in the form of a fine rain, to the bottom of the condenser, condensing the remainder of the steam.

Air and noncondensable gases are removed either by the water ejector shown in the sectional view, or else by both the ejector and a dry air pump which may be connected to the connection shown at the left. The water falling to the bottom of the shell entraps air and carries it out through the conveying nozzle at the bottom; ejector action is set up at the neck and the air supplied through the pipe is also carried out to the atmosphere.

Bulkley Barometric Condenser

This condenser consists of an iron casting, bored, ground and reamed to the required dimensions and fitted with a heavy brass cone of special composition.

Injection water enters the system at B, circulates in the belt about the brass cone C, falling through the annular space C between the outer circumference of the brass cone C, and the inner surface of the casting, forming a moving cone of water, D. Steam enters at A, and passing through the interior of cone C, meets the water at C, imparting to it the velocity it assumes upon condensation, thus tending to force more water through the annular space. Condensed steam, water and noncondensable vapors are brought down through the hollow cone of falling water D, and the noncondensable vapors discharged through contracted throat F.

The lower portion of the condenser expands until it is the same size of the tail pipe E, thus allowing the air and noncondensable vapors which have been brought through the contracted throat F, to expand, and making it impossible for them to return to the condensing chamber.

Bulkley barometric injector condensers are manufactured solely by The M. W. Kellogg Co.

General Condenser Co. Counter Current Rain Condenser

In the counter current rain condenser made by the General Condenser Co., the water of the lowest temperature is brought in contact with steam of the lowest temperature, the 2 traveling in opposite, or counter, directions.

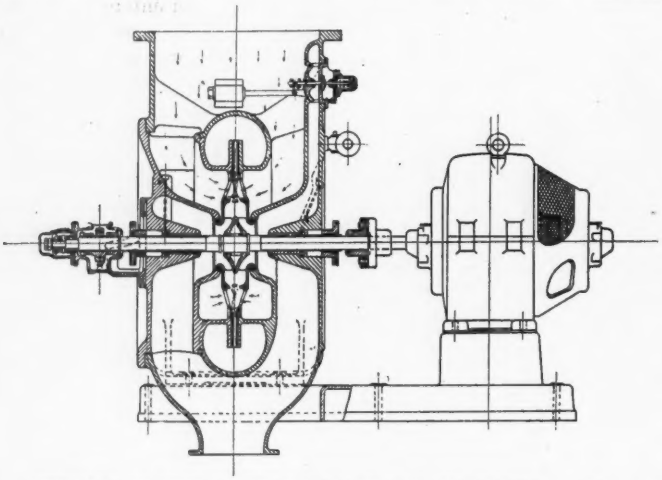
Cooling water is admitted through perforated openings in the form of a spray directly above the upper tray, from which it falls through perforations and by overflow to a second tray and from there in the same manner to a third and then to the bottom of the shell, where it passes out through outlets provided for that purpose. The 2 upper trays extend but part of the length of the condenser while the lower one is of such dimensions as to cover the entire width and length. Steam entering the shell is, by means of the above mentioned baffle, caused to flow between the second and third trays, where it is brought into intimate contact with the spray coming from the second tray and is partially condensed; it then continues on its way, passing between the first and second traps, and on into the space between the top of the shell and first tray.

Rees Roturbo Rotary Jet Condenser

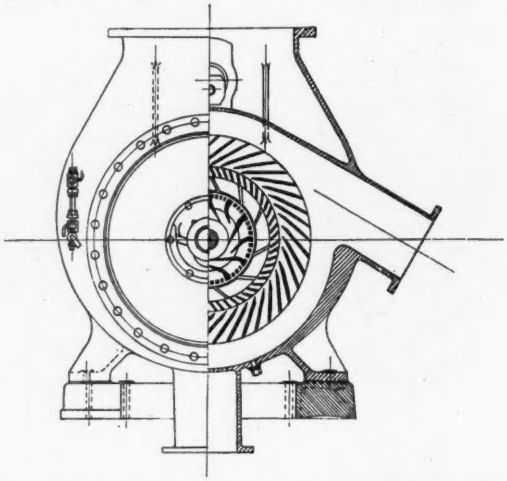
In this condenser, built by the Manistee Iron Works Co., a revolving hydraulic accumulator or pressure chamber is used to lift the water of condensation to any

height up to a limit of 20 or 25 ft. and give it an initial pressure after raising it. The condensing water, therefore, flows up the suction pipe into this revolving pressure chamber or water drum on the periphery of which nozzles are arranged which allow the water to escape from the pressure drum in radiating jets which are arranged to impinge in pairs. By this means, the water jets are made fan shaped, subdivided in a fine spray and are projected in lines radiating from the shaft, but still rotating as a whole with the impeller across a space into which the steam is allowed to exhaust.

As these fan-shaped jets are rotating edgewise at a comparatively high speed, the area swept by them is great, although the space occupied by the impeller is comparatively small. This insures an intimate mixture of steam, air and water and an excellent condition for the most rapid and perfect condensation. After the water jet has traveled radially some distance so that the broad parts of the water fans have all combined to form a complete ring of spray and condensed the steam, the problem is to extract the condensate and air



SECTION OF REES ROTURBO ROTARY JET CONDENSER



END VIEW AND PART SECTION OF REES ROTURBO ROTARY JET CONDENSER

with certainty and efficiency. The rotating jets of spray or condensate with entrained air are picked up by the blades of an exhausting impeller concentric with the rotating pressure drums and of a larger diameter, leaving a sufficient steam space between the water drum and the exhaust impeller, the whole forming a single rotary member.

These exhausting rim blades or impellers also form an automatic regulator which deals with fluctuating conditions of steam or vacuum without any speed regulation. For instance, when building up the vacuum or starting the condenser, or if the vacuum is reduced below the normal when running, the rim blades are practically empty and the condensate is swept out through these at full speed. If the vacuum rises beyond the normal, thus exerting a greater backward pull, tending to cause the trouble of choking, the rim blades fill up with water to a greater depth and because of the extra centrifugal force created by the greater radial depth, the weight of the water carried round by the fan blades exercises a greater exhausting effect when running at a constant speed.

The Koerting Eductor Condenser

In this condenser the principle of the jet is employed. This jet, created in the water nozzle, c, passes centrally through a long, cylindrically combining tube T provided with a series of holes for the passage of the exhaust steam from the condensing chamber after being admitted at E. The holes in the combining tube are drilled obliquely, directing the steam at an angle so that it impinges on the condensing jet in the direction of flow. The steam entrained by the jet is condensed and discharged together with the entrained air and noncondensable gases against the resistance of the atmosphere through the tail pipe D into the hot well.

Another condenser made by the same manufacturers is the Koerting Multi-Jet condenser, designed for condensing quantities of steam greater than those capable of being cared for by the Eductor type.

As shown, this condenser operates on the same principle as the Eductor condenser, but has instead of one central condensing jet, a number of converging jets meeting and forming a single jet in the lower part of the combining tube. This tube is cast in one piece and consists of a series of concentric nozzles of gradually diminishing bore.

Both the Eductor and Multi-jet condensers are made by Schutte & Koerting Co.

Installation of Condensers

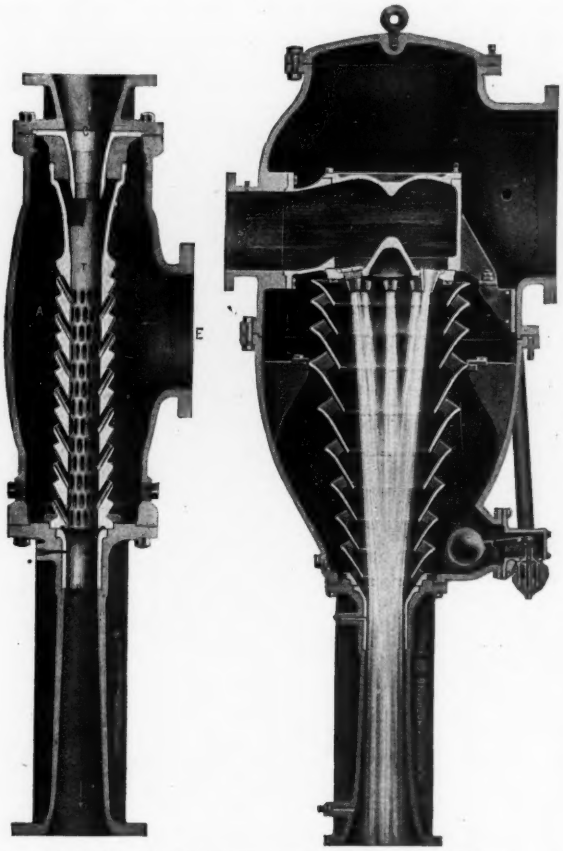
In independent condensing systems, the condenser should be placed below and as near the engine or turbine as possible, in order that the exhaust steam may gravitate toward the condenser, and in exhaust piping bends and joints should be reduced to a minimum to decrease friction and the possibility of air leakage; but siphon or barometric condensing units, due to their very nature cannot, except in rare instances, be so placed.

Due to local conditions, it may be found necessary to place jet or surface condensers on the same level as or above the engine or turbine, requiring the use of additional piping and bends. In this case, the lowest point of the exhaust piping should be fitted with a drip

which should be open whenever the engine is not operating.

High vacuum systems used in connection with steam turbines where condenser pressures of ½ lb. absolute are maintained, call for refinements not found in ordinary condensing systems. While surface condensers are generally used for this service, barometric condensers appear to find considerable favor with many designers and operators, and in either case dry air pumps are employed for the removal of air and noncondensable vapors, sometimes augmented by air coolers built inside or outside of the condenser for the purpose of cooling the air and removing any water that may remain.

Ordinary jet condensers are preferably mounted directly on the wet vacuum pump, the condenser outlet



SECTIONAL VIEW, KOERTING EDUCTOR CONDENSER
SECTIONAL VIEW, KOERTING MULTI-JET CONDENSER

and pump suction being bolted together, resulting in a short and direct passage; some forms of these condensers are provided with large condensing chambers in the bottom of which is placed a centrifugal pump for the removal of the condensate and injection water. When of the siphon or ejector types, no wet vacuum pumps are required, the function of these being performed by a barometric column or ejector action respectively.

Small condensers are generally mounted directly upon or over a combined circulating and wet vacuum pump, while the larger sized units are equipped with one or more wet-vacuum pumps directly below the bottom of the shell and an air pump also located as near as possible and connected as directly as local conditions allow.

In high-vacuum systems, for steam turbine practice, the turbine is mounted directly over the condenser, the steam connections being joined by a short copper corrugated expansion joint, and in addition to the circulating pump, a motor-driven wet vacuum pump and a steam-driven rotative dry vacuum pump are used. Surface condensers in such systems are many times fitted with air coolers placed inside the shell or inserted in the circulating water line between the condenser and the pump suction for the purpose of collecting all the condensable vapor in order to reduce the volume to be handled by the air pump.

Centrifugal condensers like the ordinary jet are preferably connected as directly and closely as possible to the engine or turbine and are generally also mounted on the suction of the wet vacuum pump which, in some instances, is built integral with the condenser.

The height of a condenser above the source of injection or cooling water supply should be as small as possible, not over 18 or 20 ft. For high lifts, such as in the case of barometric condensers, a charging valve and overhead supply will be found advantageous in starting, this, however, to be shut off as soon as the vacuum is created.

Condenser Operation

Except for the matter of cleaning and prevention of leaks, in the case of surface condensers, the question of condenser operation is more one of the operation and care of auxiliaries than of the condenser proper.

Exact detailed starting and stopping instructions can not be given to cover all types of condensers and plants other than that in independent systems, the condensing equipment should be started first, the vacuum brought up to the required degree and the engine then started; similarly in shutting down, it is necessary first to shut down the engine and then the condensing unit. In central systems, this is, however, not necessary as a vacuum is maintained in the exhaust line at all times so that the steam may be turned into the engine as soon as the exhaust valve is open. In either case, however, it is advisable to maintain close watch upon the vacuum when cutting in a new unit as due to the opening of the exhaust valve, the vacuum will tend to drop considerably.

Due to the more thorough scouring action taking place in condensers of the jet type, cleaning of the interior of the condenser is not as necessary as in surface condensers, the tubes of which should be flushed and brushed at intervals of from once a week to once a month, depending upon the nature of the water. At the same time, the ferrules at the tube holes may be taken up as the packing shrinks or as vibration loosens them.

Exhaust line leaks or those occurring in the condenser shell are generally accompanied and indicated by poor vacuum and may readily be located by going over all joints with a small flame, such as that of a tallow candle, and noting the points at which it is drawn in; leaks may also be found in the body of the exhaust piping or the condenser chamber in the form of blow holes in the castings. Joint leaks may be eliminated by taking up on the joint or repacking it, after which, while the condenser is in operation, go over the entire joint or joints, or other spots where small leaks may have been noticed,

with a good grade of black paint or shellac. This, due to the action of the vacuum, will be drawn into the tiniest holes, and stop the leak. Blow holes of any considerable size require drilling and tapping of the casting and the insertion of the proper size pipe plug made air tight by the use of white lead.

Another possible source of leak in condensers of the jet or barometric type will be found in the vacuum breaker or the atmospheric relief valve, but as this generally consists of nothing more than a leaky valve, it is a comparatively simple matter to repair.

Due to the nature of their construction, the detection, location and elimination of leaks in surface condensers is a somewhat more difficult matter than in condensers of the jet type. The most likely location of leaks in surface condensers is at the ends of the tubes where they are expanded into the tube heads or held in place by packing and ferrules. Occasionally tubes split or become pitted due to the corrosive action of the water, and in such instances, the tube should be renewed.

A simple test for the determination of leakage in surface condensers consists in putting on a full head of circulating water, maintaining a vacuum equal to that ordinarily carried, and measuring the amount of water removed by the wet vacum pump with no steam entering the condenser.

Another test applicable, however, only for the purpose of determining the existence of a leak and not its extent is to close all connections to the condenser and observe whether a vacuum once established can be maintained a reasonable length of time.

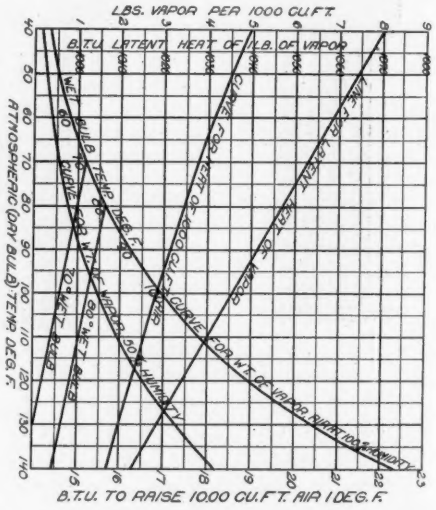
As the 2 preceding methods require considerable time and the shutting down of the unit, many power stations using salty water for cooling purposes carry on daily tests by adding a little solution of silver nitrate to a small sample of the condensed steam, and if no appreciable amount of white, cloudy precipitate is formed, the condenser is assumed not to leak.

Cooling Systems

IN LOCALITIES where cooling water for condensers, either for steam or ammonia, is scarce, it becomes necessary to reuse the cooling water which involves the problem of cooling it to a useful temperature after it has passed through the condenser. In case of ammonia condensers the water leaves at a temperature of 90 to 100 deg., and from the steam condenser it comes at a temperature of 100 to 180 deg., depending on the vacuum carried. In the case of the ammonia condenser it must be cooled to as low a temperature as possible, since a difference of 3 or 4 degrees may make a great difference in the efficiency of the plant. For a steam plant it does not pay to add the required surface to get lowest possible cooling because a larger quantity of water can be used at a higher inlet temperature and still get satisfactory results.

AVERAGE TEMPERATURE AND HUMIDITY FOR VARIOUS CITIES IN THE UNITED STATES

	Mean Values for January			Mean Values for July			
City	Humidity Per Cent	Temp. Deg.F.	Lb. Water per 1000 Cu.Ft.Air	Humidity Per Cent	Temp. Deg.F.	Lb. Water per 1000 Cu.Ft.Air	Temp.Cooled Water Deg. F.
Albany, N. Y.	80.4	23.0	.....	71.9	73.0	1.01	76
Atlanta, Ga.	76.4	42.5	0.344	75.6	78.5	1.25	81
Baltimore, Md.	71.6	34.0	.....	69.6	77.5	1.13	79
Bismark, N. D.	73.9	6.5	.....	65.3	70.0	0.80	70
Boston, Mass.	72.1	27.0	.....	71.4	72.0	0.95	77
Chicago, Ill.	82.1	23.5	.....	69.5	72.5	0.96	76
Cleveland, O.	....	....	.....	68.2	72.5	0.94	73
Denver, Colo.	52.6	29.0	.....	40.0	72.0	0.65	74
El Paso, Tex.	47.3	44.0	0.350	45.0	82.0	0.86	61
Galveston, Tex.	83.9	53.5	0.590	77.4	84.5	1.60	80
Los Angeles, Cal.	67.4	54.0	0.800	75.6	71.0	0.96	65
Milwaukee, Wis.	78.4	20.0	.....	70.6	70.0	0.88	67
New Orleans, La.	78.9	54.0	0.560	77.7	82.5	1.57	78
New York, N. Y.	75.2	30.5	.....	73.6	74.5	1.09	71
Portland, Me.	75.3	22.5	.....	76.4	68.5	0.88	67
" Ore.	85.4	38.5	0.330	64.3	67.0	0.07	62
St. Louis, Mo.	74.3	32.0	.....	66.1	79.5	1.15	74
St. Paul, Minn.	80.0	11.0	.....	66.0	72.5	0.90	67
San Francisco, Cal.	79.7	50.0	0.470	84.4	59.0	0.72	58
Wichita, Kan.	73.8	32.5	.....	66.5	79.0	1.14	75


LBS. VAPOR PER 1000 CU.FT.
B.T.U. LATENT HEAT OF 1 LB. OF VAPOR
ATMOSPHERIC (DRY BULB) TEMP. DEG. F.
WET BULB TEMP. DEG. F.
CURVE FOR WT. OF VAPOR PER CU.FT. AT 100% HUMIDITY
B.T.U. TO RAISE 1000 CU.FT. AIR 1 DEG. F.

CONSTANTS FOR COOLING SYSTEM CALCULATIONS

Factors in Cooling

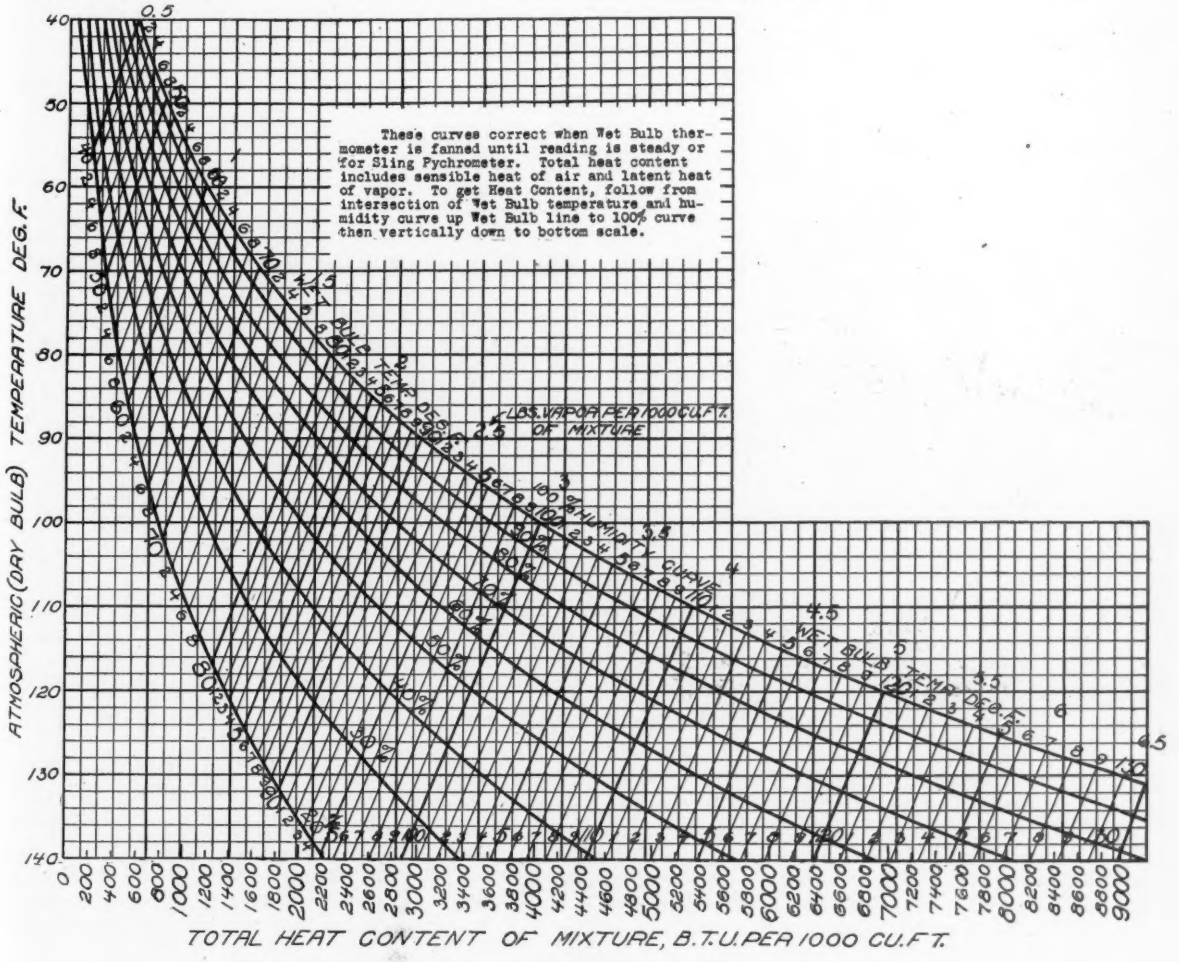
Cooling of the water is accomplished in 3 ways—by radiation, by convection and by evaporation. Radiation or the conducting of heat to the air by piping and parts of towers or other apparatus is a negligible factor; convection or transfer of heat direct to the air by contact is a larger factor, while evaporation or the conversion of a part of the water into vapor by taking up latent heat accounts for 75 to 85 per cent of the cooling effect. By this evaporation water is lost and must be supplied, the loss varying from 3 up to 10 per cent, according to the conditions of cooling.

The amount of moisture that can be carried away by air depends upon the temperature at which the air enters and leaves the percentage of humidity at the inlet. Air does not absorb moisture, but air and water vapor occupy the same space at the same time and the effect that the air has in determining the amount of moisture in a given space is the temperature at which the air exists, since that determines the amount of moisture possible in that given space. Air movement is of help simply by carrying away the vapor as it forms, thus leaving the space free for the formation of further

vapor. It is, however, convenient to speak of the air as containing vapor since it is with the temperature and amount of the air passing through a cooling tower or other system that we have to deal.

A pound of air at 72 deg. F., and 70 per cent saturation raised to 102 deg. and 100 per cent saturation will take up by evaporation 28.7 B.t.u., and by convection 7.2 B.t.u.; hence, under these conditions, the evaporation is 4 times as effective as the convection.

Evidently the action of both convection and evaporation depends on the amount of water surface brought in contact with the air, since direct transfer of heat can take place only at contact surfaces, and evaporation of vapor can only take place from the water surface. The problem in any cooling system is, therefore, to present as large a possible surface of water to the air and to bring as large an amount of air as possible in contact with the water surface.


These curves correct when Wet Bulb thermometer is fanned until reading is steady or for Sling Pychrometer. Total heat content includes sensible heat of air and latent heat of vapor. To get Heat Content, follow from intersection of Wet Bulb temperature and humidity curve up Wet Bulb line to 100% curve then vertically down to bottom scale.
ATMOSPHERIC (DRY BULB) TEMPERATURE DEG. F.
LBS. VAPOR PER 1000 CU. FT. OF MIXTURE
HUMIDITY CURVE
WET BULB TEMP. DEG. F.
TOTAL HEAT CONTENT OF MIXTURE, B.T.U. PER 1000 CU. F.T.

PSYCHROMETRIC CHART OF VAPOR WEIGHTS AND HEAT CONTENT OF AIR

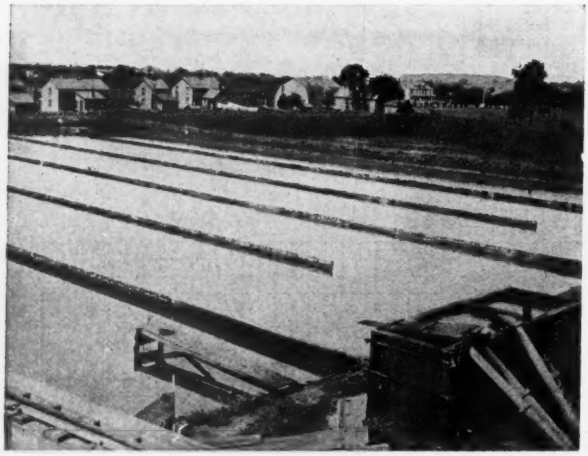
Humidity

When saturated, a space contains all the water vapor that it can hold, or 100 per cent, and we speak of this as 100 per cent humidity. The higher the temperature the greater the amount of water vapor which can be carried. The per cent of humidity will depend also on weather conditions and location. Near a large body of water, humidity will be greater than in the middle of a dry plain, and in moist weather the humidity will be greater than on a dry, hot day. It is evident, therefore, that the proportions of any cooling system must be determined by the most unfavorable conditions, which are usually encountered in a moist day in July, and to determine the probable conditions to be met, the records of the United States weather department give the most reliable data.

The table herewith gives values of humidity, averaged for January and July, the average temperature, the pounds of water carried in July for 1000 cu. ft. of air and the probable temperature to which water may be called by a well proportioned cooling system. Greater cooling can be secured in winter on account of the lower air temperature, even though humidity is higher.

Determination of the humidity is made by means of wet and dry bulb thermometers, either stationary or in sling form, the combination being known as a psychrometer. The dry bulb thermometer is of ordinary type, while the wet bulb has the bulb surrounded with a close-fitting muslin bag supplied continuously with moisture by a wick, the evaporation of the moisture lowering the temperature of the bulb according to the rapidity of

the evaporation. Objection to the stationary form is that air around the wet bulb moves slowly, impeding evaporation. This can be partly overcome by fanning the bulbs of the thermometers until the wet bulb temperature becomes stationary, and so treated the readings will be comparable with those of the sling psychrometer which is a device having the 2 thermometers mounted so that they may be rapidly revolved around a handle, thus giving a wind effect. Evidently evaporation will be in proportion to the ability of the air to take up moisture, hence the difference in temperatures will be an index of the humidity of the air, and this may be determined from psychrometric tables recently published by the Wheeler Condenser & Engineering Co., which give the dry and wet bulb readings, dew or saturation temperature, humidity and pounds of water vapor per thousand cubic feet over a wide range, or the humidity and weight of air carried may be determined from hygrometric chart given herewith, which has been plotted from the Wheeler tables and others.



COOLING POND WITH PARTITIONS TO INCREASE CIRCULATION

Experience has shown that with a well designed cooling system water may be reduced within about 5 deg. of the wet bulb temperature, and air heated to within 5 deg. of the incoming water, but this involves careful consideration of the temperature and humidity of the air, provision of sufficient cooling surface for towers or ponds of sufficient nozzle capacity for spray systems, and in the case of atmospheric cooling towers the condition of prevailing winds must be taken into account. Since the amount of air which comes in contact with the water is a determining factor, in the cooling, it becomes important, especially with towers, to find how much air must be supplied for a given weight of water to be cooled. The hygrometric tables, of which the best are those prepared by C. F. Marvin, and published by the Weather Bureau of the Department of Agriculture, usually give the moisture for any given humidity in grains per cubic foot, but a more convenient measure for cooling system work is the number of pounds per thousand cubic feet. The change may be made by remembering that there are 7,000 grains in one pound, and as one grain per cubic foot would be 1000 grains for 1000 cu. ft., 1 grain per cubic foot will equal 1/7 lb. of moisture per 1000 cu. ft. of air.

Cooling System Calculations

From the known conditions under which the cooling system will work, we can find the pounds of moisture per thousand cubic feet for the air on entering and leaving, and the difference multiplied by the increase in volume of the air, due to increase of temperature in passing through the cooling system, will give the vapor taken up by a thousand feet of air. This times the latent heat for the vapor at the temperature when it leaves the system, and will give the heat taken up by the air, which must, of course, equal the heat removed from the water.

As an example in cooling tower calculation, assume a dry bulb temperature of 85 deg., and wet bulb temperature of 74 deg.; that water comes to the tower at 120 deg., and is to be cooled to 80 deg.; and that outgoing temperature of the air will be within 5 deg. of the inlet temperature of the water or 105 deg., and the humidity 100 per cent. From the psychrometric chart, for 85 deg. dry bulb and 74 deg. wet bulb the humidity will be 60 per cent and the moisture carried will be 1.1 lb. per 1000 cu. ft. At 105 deg. and 100 per cent humidity the moisture per 1000 cu. ft. is 3.28 lb., so that the difference will be 2.18 lb. In addition, the volume of the air is increased in proportion to the absolute temperature which is Fahrenheit reading plus 460 deg., or the inlet temperature is 85 plus 460 equals 545, and the outlet temperature 105 plus 460 equals 565. Dividing 565 by 545 gives 1.036 the ratio of increase of volume, and multiplying 2.18 by this gives 2.26 lb. of moisture taken up by each thousand cubic feet of entering air.

This moisture will be carried away at 105 deg., hence each pound will have taken up the latent heat corresponding or 1033 B.t.u., as shown from the curve for latent heat on the Chart of Constants and the total heat carried by 1000 cu. ft. of air due to evaporation will be 2.26×1033, or 2340 B.t.u.

From the curve for specific heat of 1000 cu. ft. of air at constant pressure taken at the average temperature of the air at 95 deg., we find the value 17, and multiplying this by 20 the temperature rise gives 340 B.t.u. per 1000 cu. ft. taken up by convection, in heating the air itself. This, added to the heat taken up by evaporation, gives a total of 2680 B.t.u. taken up by each 1000 ft, of entering air.

Each pound of water cooled gives up $120 - 80$, or 40 B.t.u., hence, 2680 divided by 40 gives 67 lb. of water cooled by each 1000 cu. ft. of air. If we assume that 15 lb. of steam are required per engine-horsepower-hour and that each pound of steam requires 30 lb. of cooling water to condense it, we have 15×30, or 450 lb. of cooling water per hour per horsepower, and this divided by 67 gives 6.715 thousandths of cu. ft. air per hour per horsepower. Multiplying by 1000 and dividing by 60 gives 111.7 cu. ft. of air required per minute for each engine-horsepower.

To find the percentage lost by evaporation, we add to the 67 lb. cooled the 2.26 lb. lost by evaporation, giving 69.26 lb. entering the tower. Dividing 2.26 by this, gives 3.26 per cent as the loss due to evaporation.

Values of total heat content per 1000 cu. ft. of air at the right of the Psychrometric Chart, furnished by

the Wheeler Condenser & Engineering Co., simplify the calculation. At 105 deg. and 100 per cent humidity, the heat content is 4800 B.t.u. per 1000 ft. of air. At 85 deg. and 60 per cent humidity the heat content is found by following from the intersection of dry bulb and humidity lines, up the wet bulb diagonal to the 100 per cent curve and then vertically down. The value is 2200 B.t.u., the difference being 2600 B.t.u. taken up by each 1000 cu. ft. of entering air. This does not agree exactly with the former value, 2680, but is within a per cent as close as calculations of this kind can be made.

It is important that proportions shall be kept such that the outgoing temperature of the air be as near as possible to the incoming temperature of the water as a few degrees rise in air temperature will make a considerable difference in the amount of air required. If in the above example the outgoing air temperature were 110 deg., the heat content from the curves at 100 per cent humidity would be 5500 B.t.u., and subtracting the content at 85 deg. and 60 per cent humidity would leave 3300 B.t.u. taken up per 1000 cu. ft. of air as against 2600 B.t.u. taken up for 105 deg. outgoing temperature. This is an increase of 700 B.t.u., sufficient to cool more than 10 lb. of the incoming water, or 77.6 lb. water cooled per 1000 cu. ft. of air. It would reduce the air required proportionately, hence dividing 111.7 by 77.6 and multiplying by 67, we get practically 96.5 cu. ft. of air required per minute per horsepower, a reduction of 13.6 per cent in air required, which would cut down the fan power in a fan draft tower, or reduce the air velocity and the tendency to cause spray in the case of a natural draft tower.

Types of Cooling Systems

Three types of cooling systems are in use, the cooling pond, which may be natural or artificial, and is usually supplied with a series of partitions so that incoming hot water must travel over the entire area of the pond before reaching the point from which the condenser supply is drawn; and which often has, in addition, wooden troughs to carry the water in contact with the air over considerable distances before being distributed to the pond, and also not infrequently has some arrangement of steps or baffles over which the water flows in a thin film in order to increase the cooling surface.

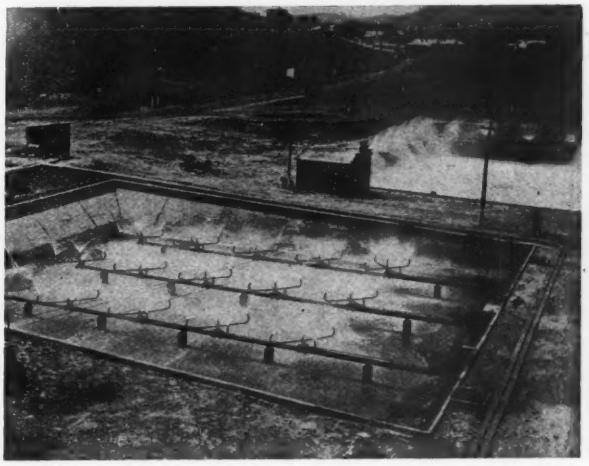
The second general system is the cooling tower method of which there are 3 classes, the atmospheric, the natural draft and the forced draft, in all of which a filling is provided to break up the water into drops and films so as to increase the area of water surfaces, and provision is made for an upward current of air to carry away the vapor.

The third system is the spray nozzle method used in connection with cooling ponds, the principle being to discharge the water from nozzles in a fine spray which, as it falls to the surface of the pond, will have intimate contact with the rising currents of air induced by the high temperature of the sprayed water. In all cases the greater the amount of water surface which can be presented to the air the nearer can the water be cooled to the wet bulb thermometer temperature. The importance of this point is evidenced from the fact that for steam turbine practice increasing the vacuum in a turbine from 26 in. to 27 in. results in a gain in fuel economy of 5 per cent; increasing from 27 to 28 in. gives a further gain of 6 per cent, and increase from 28 to 28½ in. will give a further gain of 4 per cent. Higher vacuum requires, however, colder condensing water; thus at 26 in. vacuum the temperature required is 95 deg., at 27 in. 85 deg., at 28 in. 102 deg., and at 28½ in. 60 deg., these figures being based on a temperature 30 deg. less than that of the steam in the condenser, in order to secure efficient operation.

Another advantage of the cooling system over a natural supply of cooling water is that by supplying sufficient reservoir capacity, cooling water is insured in proper amount regardless of periods of drought or ice formation, the reserve provides for overloads and secures clear water for use in the condenser and in the case of ice plants permits of using a large volume of water, thus reducing the head pressure and the work to be done by the compressors. Also if a pond is used it becomes a reservoir for fire protection.

Cooling Ponds

Taking up the classes of systems in the order named, which is the order in which they came into use, we have first the pond, natural or artificial with bottom usually of puddled clay, and banks of clay or masonry. Estimates vary as to the amount of surface required, but



SPRAY TYPE COOLING POND, SPRAY ENGINEERING CO.

authorities give roughly that 1 sq. ft. of cooling surface will be required for each 500 B.t.u. to be given up per hour. This will depend largely upon the method used for delivering water to the pond and circulating it in the pond. After passing over an apron, the discharge should be released on the top of the pond, and partitions placed to insure passage of the water back and forth over the surface, the supply for the condenser being drawn from the bottom of the pond, at the point most remote from that at which it is delivered to the pond. The depth of such a pond should not be more than 4 ft., and under these conditions from 0.4 to 0.5 gal. of water can be cooled per minute for each square foot of pond surface.

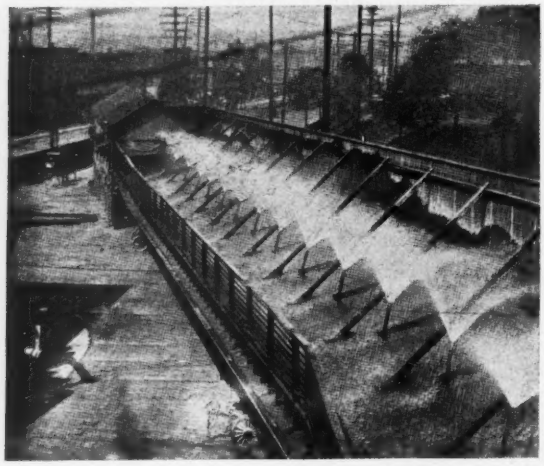
By the use of grill work towers or piles of brush in racks over which the water flows as it is delivered to the

pond, the cooling effect can be much increased, these devices being practically a crude form of atmospheric cooling tower. Evidently in hot weather, when the dry bulb temperature is high and particularly in a location where the humidity is high, this method is not as effective as in cooler weather and a dry location. Its chief recommendation is low first cost.

In cases where makeup water for the steam system is taken from the cooling water this makeup should be drawn from the outflow pipe of the condenser so as to retain as much as possible of the heat taken from the condenser steam.

Cooling Towers

Of necessity any data given in regard to the size and operation of cooling towers must be used with much discretion since the action varies so greatly with the local conditions. In the atmospheric type which consists of a filling or grill work over which the water passes downward in films and drops while the air flows upward, due to the heating, the tower is left open if in locations where the spray does no harm, or is surrounded by a series of louvers or inclined boards which prevent the spray from being blown away by wind and also



ROOF INSTALLATION OF SPRAY SYSTEM, BY SCHUTTE AND KOERTING

to prevent loss of cooling water which might be blown out of the tower. Experience is about the only safe guide in determining the size of this type of tower, since air enters the tower at all points in its height and the wind will have a large effect in determining the efficiency of its action. In order to make sure that the air currents shall be effective at all parts, such towers are usually narrow as compared to their length, the long way being placed facing the prevailing wind.

Roughly, 1 lb. of water being evaporated will take up 1000 B.t.u. and this will cool 50 lb. of water through a temperature drop of 20 deg. The temperature of the water leaving the tower may be estimated from a rule given by the Cooling Tower Co., as follows: Add together temperature of the air or dry bulb thermometer, twice the temperature of the wet bulb thermometer, and the temperature of the inlet water, and divide by 4, and the quotient will be the temperature of the outlet water.

Approximate ground plan dimensions for its atmospheric cooling towers as based on an average height of 30 ft. above the basin at the bottom, are given by the Cooling Tower Co., as shown in the table herewith:

Approximate Ground Area for Mitchell-Tappen Atmospheric Towers

Gal.per hr.	Dimensions, ft.	Gal. per hr.	Dimensions, ft.
1500	10.7 by 7.7	12,000	19 by 19
3000	10.7 by 10.7	18,000	19 by 24.7
4500	10.7 by 13.7	24,000	19 by 30.5
6000	10.7 by 16.7	30,000	19 by 36.3

The atmospheric tower is low in first cost and has practically no operating expense, but of course requires a larger tower than the natural draft or forced draft, approximately 1.5 gal. per min. being cooled for each square foot of ground area, while in the fan draft type 6 to 7 gal. per min. can be cooled for each square foot of ground area. Manufacturers of cooling towers usually guarantee their performance on a basis of 75 deg. dry bulb temperature and 70 per cent humidity for the incoming air, the guarantee covering cooling of a specified amount of water from a maximum inlet temperature to a minimum outlet temperature.

For towers with boards set on edge at right angles, approximately 1 sq. ft. of ground area will be needed for 25 gal. of water to be cooled per hour in towers of large sizes of an average height of 15 ft.

APPROXIMATE DATA FOR FAN DRAFT TOWERS

Cooling Capacity Gal. per Hr.		Height Ft.	Area of Tower Base	Horsepower Served Comp.Cond.Eng.	Size & No. of Fans	Aver. R.P.M.	Aver. Fan Hp.
Ammonia	Steam						
2100	4200	25	19 x 19.5	50	1-6 ft.	110	1.25
3100	6200	25	19.8x20.0	75	1-6 ft.	160	1.75
4200	8400	25	20 x 20.8	100	1-7 ft.	145	2.25
6250	12500	25	21.5x22.5	150	1-8 ft.	145	3.50
8300	16700	25	23.3x24.5	200	1-9 ft.	135	5.50
11500	21000	26	24.5x25.3	250	1-10ft.	135	8.00
12500	25000	26	26.5x27.0	300	1-10ft.	145	11.00
17100	34200	27.5	27.5x29.5	400	1-12ft.	115	14.00
20750	41500	27.5	29 x 30.0	500	1-12ft.	145	18.00

In the natural draft or chimney type of cooling tower, the filler section is enclosed in a tight casing of wood or steel and an extension of this is carried above the filler to give a chimney draft due to the difference in weight between the rising column of hot air and the air outside. The filler is raised above the receiving basin at the bottom sufficiently to give space for the inflow of air beneath. This type is less dependent upon the activity of the wind than is the atmospheric type, but on the other hand it does not take advantage of such wind as may be stirring, except as such wind blowing across the top of the chimney may increase the draft. Any condensation of spray in the chimney will, however, be returned to the filler, and a reduction thus made in the loss by evaporation. This type also does away with any possibility of loss of cooling water from "drift" due to the blowing of wind and will be more effective where the outside temperature is comparatively low

than will the atmospheric type. Low velocity of air also permits the outlet temperature to come nearly to that of the inlet water. As to dimensions of this type, an Acme tower, made by B. F. Hart, Jr., with a capacity of 250 gal. a min., designed for a dry bulb temperature of 80 deg., and 80 per cent humidity, was constructed with 5 decks, 7 ft. apart, each deck having 77 sq. ft. of pans, and covered a ground area of 14 by 18 ft., with height of 35 ft. The total height to which cooling water must be raised was 65 ft., and this required a centrifugal pump, installed by the American Well Works, and requiring 7.8 hp. Test of the tower showed cooling to 79 deg. in July and August and to 69 deg. in September. Two towers erected in Edinburgh, Scotland, having capacity of 210,000 gal. per hr. with dry bulb temperature of 50 deg., and 85 per cent humidity, were made 40 ft. square at the base and 130 ft. high to cool the water from 105 deg. to 80 deg. The walls were of ornamental masonry and the filler of boards arranged in steps.

For fan towers the construction is similar to that for natural draft, except that the chimney is shorter and fans are employed to give forced draft, thus increasing the amount of air circulation and therefore the effectiveness of the cooling surface, but it must be remembered that crowding the filling in a tower in order to increase the surface, also increases the resistance to air flow and therefore the horsepower required to drive the fan. Also small area of cooling surface in the filler cannot be made good by increasing the fan speed or size and giving a higher air velocity, since water surface is necessary in order to permit of evaporation.

The fan draft tower is much smaller than either atmospheric or natural draft, and the ground area required is less. It is therefore well adapted for installation on roofs or in crowded areas, and has the advantage that it can be forced in summer, so that where heavy load must be carried at that season it has an advantage. Where the load is light in summer and heavy in winter, as in the case of electric light plants, the natural draft has the advantage that its capacity increases with decrease of atmospheric temperature.

To give an idea of size required, a tower to care for the steam from a 1000-hp engine might be 17 ft. in diameter and 30 ft. high, and with a hot well at the base 8 ft. diameter by 7 ft. deep, having 2000 gal. capacity. Gueth estimates that the power required for fans and pumps in a fan type tower will be from 4.5 to 6 per cent of the engine power served, and that approximately 0.4 sq. ft. of cooling surface will be required for each horsepower of a compound condensing engine. The table herewith, compiled from various sources, gives an idea of the dimensions of fan draft towers for different capacities, the size of engine which will be taken care of and the fan power required. For pumping, with any type cooling tower, the height to which the water will be raised on account of the tower will be approximately 30 ft., and if the system is made closed, that is, the pipe from the cooling tower reservoir to the condenser, from there to the circulating pump and from the circulating pump to the top of the cooling tower, is made a continuous system, the only head against which the pump will work will be the height of the tower and the friction in the piping and condenser, since the upflow of the heated water from the condenser will be more than balanced by the downflow of the cooled water from the tower. Power required for the pump alone will vary from 1.5 to 3 per cent, depending on the height of the tower, the distance to which water must be pumped and the type of pump used.

Spray Cooling Systems

Spray cooling provides large heat radiating and evaporating capacity at low cost for power, for installation and for depreciation, and small loss from evaporation. The spray system has also great flexibility, since it can be operated at half pressure or less for cool weather and give satisfactory results.

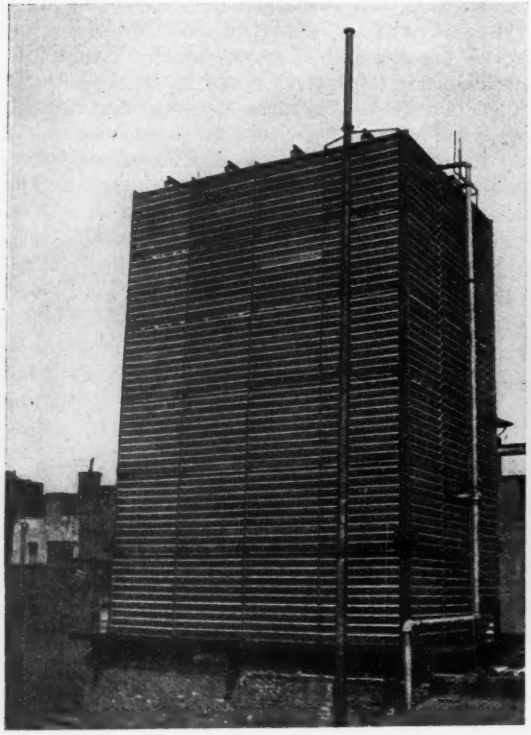
In this system the discharge piping from the circulation pump is extended out over the surface of a pond and nozzles are attached of form specially designed to give a wide cone of spray. The nozzles are usually set at an angle in order to give better air circulation through the spray and require from 5 to 7 lb. pressure at the nozzle. High pressure gives greater cooling capacity, but pressures above 10 lb. are found uneconomical. The pipes are placed from 20 to 25 ft. apart, at some 2 ft. above the surface of the pond, and the pond area is made sufficient to give 1 sq. ft. of surface for each 200 lb. per hr. to be cooled, in sizes for 1000 kw. and under, and for 1000 to 5000 kw., 1 sq. ft. is provided for 250 lb. per hr. The depth of the pond is made not over 5 ft.

Drift of water from the sprays by reason of wind blowing is not as great as would be expected, amounting to not over 2 per cent of the water sprayed, and unless the pond is nearer than 30 ft. to a building, no fence is required. If it must be placed near a building, louver fences are provided to catch the drift. Walls and bottom of the pond are the same as for the cooling pond system alone, and nozzles often are arranged in groups as shown in the illustrations herewith. It may be arranged in 2 decks, one above the other, which requires less ground space, but on account of the greater distance which the spray must fall the loss from drift is likely to be greater. The pond should be provided with a suction well of concrete, which is properly double screened to prevent drawing of any foreign matter into the condenser and has an overflow and means for draining and cleaning.

Where space is limited the spray system may be installed on a roof, as shown in the illustration of the Schutte & Koerting system herewith, the only change required in the roof being that tar and gravel be removed and additional layers of roofing felt mopped liberally with good roofing compound be applied, carrying the felt well up on the sills of the louvers to give a basin for the cooled water. It is not good practice to use this where the water will be over 125 deg., as the tar will be affected. For higher temperatures use rock asphalt mastic for a roof covering, and provide several down-spouts at the low side to carry off the water rapidly. To prevent drift of spray to surrounding buildings, louvers of cypress, yellow pine or galvanized iron should be used, carried to a height above the highest point of the spray, as shown in the illustration.

By using a double spraying system, returning part of the cooled water to the hot well and passing it again through the nozzles, a greater cooling effect may be produced.

For a double spraying system the hot well capacity should be increased to practically twice what it would have for a single system and the capacity of the pump sending water to the spraying system should be twice that required by the flow of cooling water through the condenser. If desired, two single systems may be used, one in series with the other, in which case each pump would have capacity equal to the condenser flow. A roof 30 by 43 ft., will have sufficient area for a single spraying system to handle 400 gal. a min., or a double spraying system handling 200 gal.; 50 by 43 ft. will take



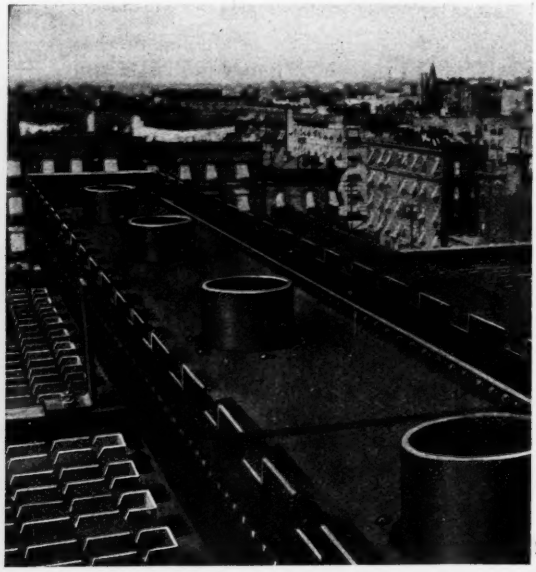
BURHORN ATMOSPHERIC TYPE TOWER

care of 800 gal. single spraying, or 400 gal. double spraying; 50 by 56 ft. will care for 1200 gal. single spraying or 600 gal. double spraying.

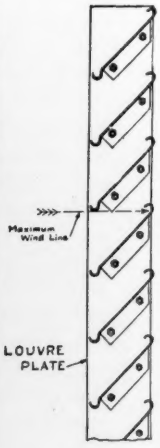
Two important points in connection with a spray system are proper design of nozzles and correct laying out of the system. On the nozzles depends the task of breaking up the water into particles so that relatively great areas shall be exposed for cooling by contact with air and by evaporation. Under ordinary conditions power necessary to operate the sprays will average between 1 and 1.5 per cent of the power generated by the engine, and tests have shown that yearly average loss of water from evaporation and drift will be not over 1.5 per cent of the condensing water used.

Economy of Cooling

To determine whether an installation of a cooling system is warranted in any given case, it is necessary to compare the cost of city water used or the cost of pumping, if water is obtained from river or wells, with the fixed charges on the first cost of the cooling system plus the cost of operation and maintenance. In this estimate it is necessary to consider carefully the factors involved and to compare also the claims of each system of cooling, keeping in mind the cost as above outlined and also the reliability, certainty of action and demand for makeup water in the cooling system as compared with the supply available. Where there is a plentiful supply of cooling water to be had for pumping it a short distance, usually a cooling system is not economical, and in case a cooling system is installed it is necessary to allow for the addition of 2 to 5 per cent makeup water each time that the cooling water is re-circulated. In case barometric or jet condensers are used, where the condensed steam is added to the cooling water, this will be sufficient ordinarily to make up for the evaporation loss in the cooling system.



TOP DISTRIBUTING SYSTEM OF BURHORN TOWER



END SECTION OF BURHORN LOUVRES

Some examples of cooling tower performance have been quoted, and test of a plant at Laurel, Miss., employing a spray pond system having 30 2-in. bronze turbine spray nozzles arranged in 6 groups of 5 nozzles each with total capacity of 1200 gal. a min., operating at 7 lb. per sq. in. pressure at the nozzles and a pond 50 by 115 ft., cost entire material for the system, including nozzles, equipment, pipe fittings, etc., $700, the labor required for assembling being additional. The system maintains the vacuum at 27.5 in. during the hottest weather.

In the roof installation shown in the illustration, 48 3-in. nozzles with capacity of 150 gal. each, at 6 lb. pressure, or a total of 7200 gal. a min. reduced the temperature of the cooling water from 92 deg. to 72 deg., with dry bulb temperature 70 deg., and humidity 65 per cent.

In estimating the power required for handling a cooling system, 1.5 per cent of the engine power served should be allowed for a spray system, 3 per cent for the pumping in a tower system, and 4 per cent for fan and pumping in a forced draft system.

Burhorn Natural Draft Towers

Towers made by the Edwin Burhorn Co. are principally of the atmospheric type, and are provided with unit cooling surfaces, each unit consisting of a series of parallel troughs notched on the 2 sides and resting on a similar series of parallel angle pieces running at right angles, bolted together with ⅜-in. bolts and double washers, thus stiffening the troughs so that they remain level when full of water. The units are fastened to channel iron beams by clips and through bolts, requiring no punching of the channels. This construction causes the water to seek its level in the troughs, no matter how it enters them from above, so that it leaves them uniformly through the notches the entire length. Water from each notch strikes a supporting angle at the center and flows down the sides equally to the unit below, no water being able to pass directly through; yet the air passes freely around all parts, thus reaching a large water surface.

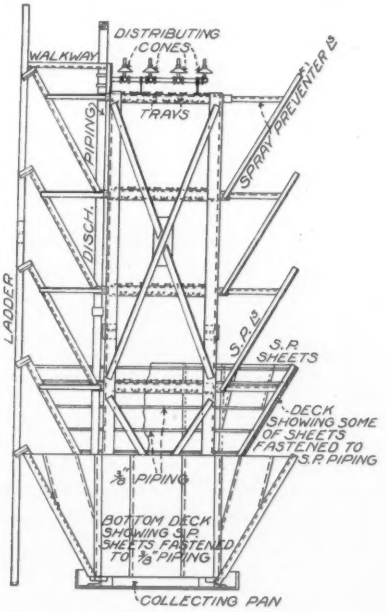
Troughs in one deck are at right angles to those above and below, which permits the water blown toward the leeward side of the tower to flow backward toward the windward side, at every alternate deck.

Distribution at the top is from a main trough in the center of the tower and running nearly its full length, which is divided by a lengthwise partition into upper and lower compartments; water enters the lower compartment at one end through a tapped flange, and a similar flange at the other end serves in cleaning out. From this compartment the water rises in vertical pipes, adjustable to regulate even distribution, through the partition and overflows into the upper compartment, whence it escapes by notches to cross distributing troughs and from these to the upper cooling decks.

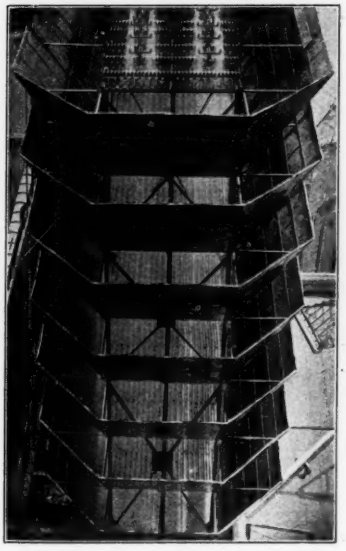
All parts are made of galvanized iron and dipped in a protective compound to prevent corrosion from dissolved acids and other impurities which may be carried by the water. Tests show a cooling of the water to within 1 to 3 deg. of wet bulb temperature.

Mitchell-Tappen Atmospheric Towers

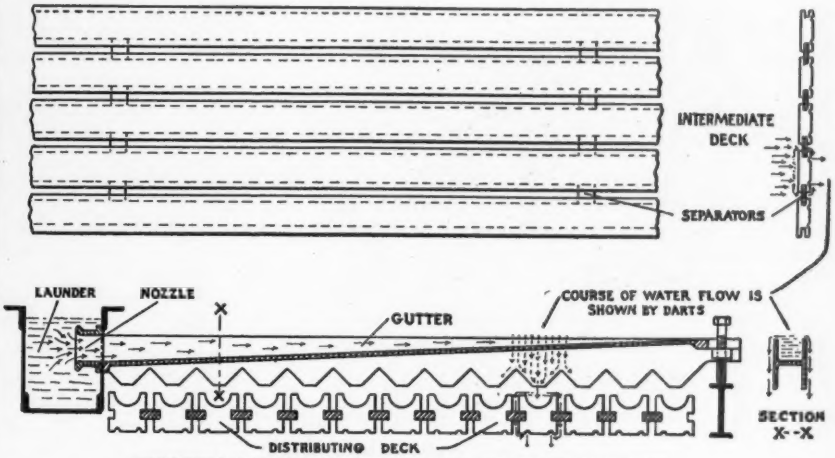
Mitchell-Tappen towers made by the Cooling Tower Co. have a structural steel frame, enclosing and supporting a series of wooden decks, with a distributing system of steel and cast iron at the top. The exterior is a series of vertical latticed girders carrying the louver



SECTION OF HART COOLING TOWER



TOP VIEW OF HART COOLING TOWER



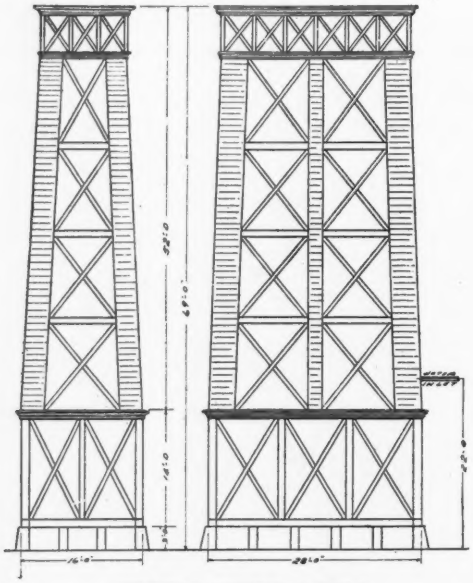
MITCHELL-TAPPEN NATURAL DRAFT TOWER SECTION OF DISTRIBUTING SYSTEM AND GUTTERS

Surrounding the tower is a casing of steel louvers with curved edges, which act as baffles to catch and return all spray. The spacing is such that there is no chance for direct blowing of wind through the tower, and makeup water is reduced to 1.5 per cent of the total amount circulated.

system, which prevents water from blowing out of the tower, and at the base is a steel, wood or concrete collecting reservoir, as shown on p. 1.

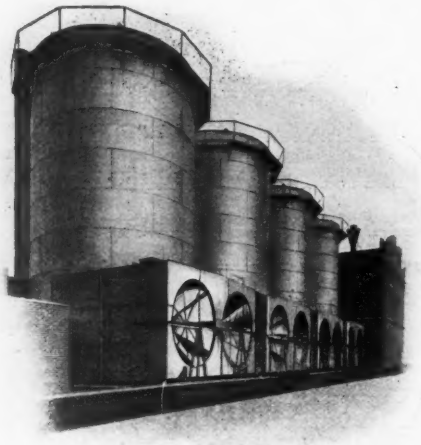
For the frame, vertical riveted latticed girders are joined lengthwise and crosswise by angle and I beam struts with tie rods and clevises to make all taut. The

design is proportioned for a wind pressure of 30 lb. per square foot on all exposed areas, and in addition a lift of 12 lb. per square foot acting on the louvers. All parts are treated with one coat of protective paint before shipment, and a second after erection; and can easily be repainted at any time.



STOCKER CHIMNEY TYPE

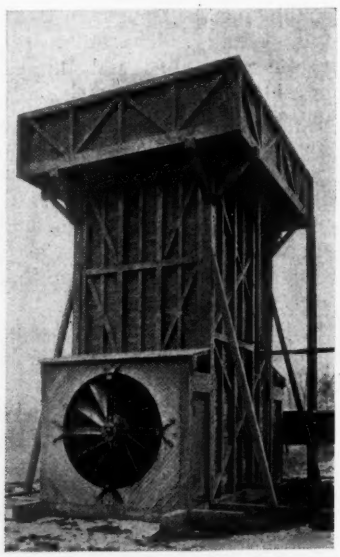
Cooling decks are of swamp cedar bars guaranteed for 10 yr., of special form, to subdivide the water, laid flatwise with separators at intervals to preserve alinement. Water, falling on these bars, is broken into spray, then flows down the sides and drips from 2 bottom grooves.



BATTERY OF RUEMELLI-DAWLEY FAN DRAFT TOWERS

Distribution at the top is from a launder through nozzles having 2 in. square opening into cast-iron gutters over the sides of which the water flows and drops from the drip points into gutters whose under sides are shaped like the bars. The main gutters are adjustable by leveling screws to give uniform overflow throughout their lengths.

For winter use, a secondary distribution system of nozzles attached to a horizontal length of pipe discharges water to the tower at a distance below the top so that but part of the cooling surface is utilized, thus avoiding cooling below the freezing point, and reducing the pumping head. The distributing systems are furnished complete ready for the pipe connections.

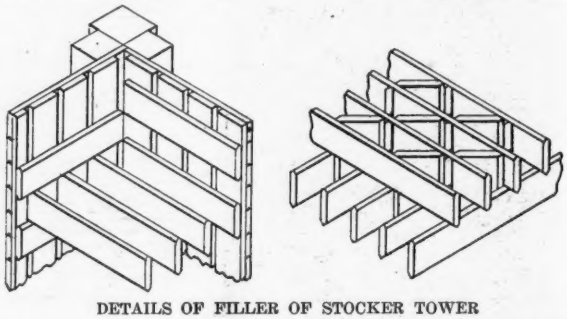


STOCKER FAN DRAFT TOWER

Louvers are of corrugated galvanized steel or of tongue and groove boards bolted to the steel frame at an angle of 45 deg., and spaced to prevent loss of water from wind and yet give minimum resistance to air circulation. Around the top of the tower is a 2-ft. walkway protected by a railing 3 ft. high, giving access to all parts of the distributing system for regulation and cleaning.

Hart Natural Draft Tower

In the open type natural draft tower made by B. Franklin Hart, Jr., & Co., cooling decks are equipped with Hart trays, about 3 in. wide and of length to suit the width of the tower, placed on the upper and lower flanges of I beams and channels which form part of the supporting structure.



DETAILS OF FILLER OF STOCKER TOWER

The trays are spaced 6 in. apart staggered, the rows of trays in each deck being 3 in. apart, thus giving 3 in. air space between trays at all points for free circulation of air. Decks are spaced 7 ft. apart, the long drop re-

sulting in a splashing effect in all directions and breaking up the water into a fine mist resembling steam.

Shields set at an angle on steel framework form a spray preventer and assist air circulation.

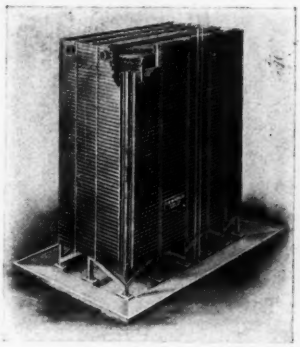
Distribution of the water at the top is by means of branch pipes and cones which spread the fall uniformly over the top deck.

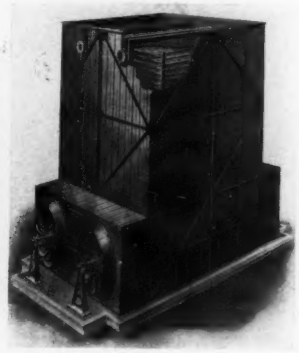
A ladder and walkway give access to the distributing system.

Ruemmeli-Dawley Forced Draft Tower

Block steel, galvanized, wood, brick or concrete are used as material for the towers erected by the Ruemmeli-Dawley Mfg. Co. When steel towers are not galvanized, all steel work is carefully painted with suitable protective coating. When galvanized, the steel work is punched and formed, afterward heavily galvanized, so that the coating is continuous and undisturbed by manufacturing operations. The towers are round or square as may best suit conditions and location.

Even distribution of the water over flat surfaces resulting in flow in uniformly thin sheets over which air is blown by a fan is the special feature of these towers. At the top is a gallery from which the distributing troughs are accessible; water passing from these troughs to the wood lining below is met by the upward current of air, and, after cooling, collects in a basin at the bottom.





C. H. WHEELER MFG. CO. ATMOSPHERIC TOWER
C. H. WHEELER FORCED DRAFT TOWER

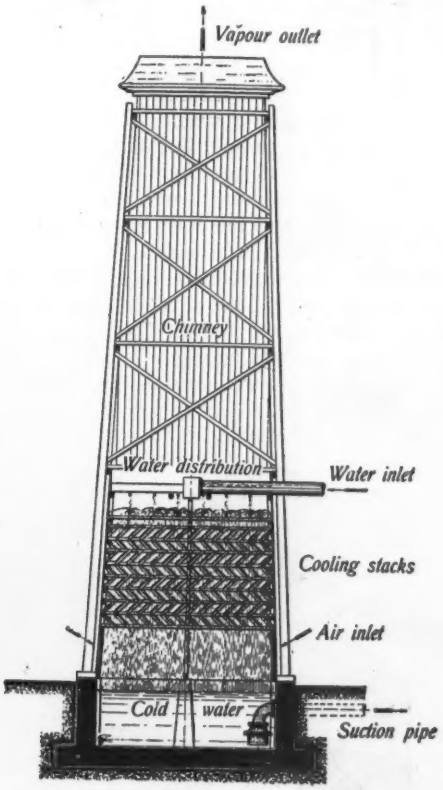
Fans of the cone type are used, set in housings at the base of the tower, and deliver to a chamber below the filling, the drive being on the far end of the shaft, by motor, engine or belting as most convenient.

Stocker Natural Draft Towers

In the natural draft cooling towers manufactured by Geo. J. Stocker, the filling or cooling surfaces is a checkerwork of heartwood swamp cypress boards set on edge in horizontal layers with vertical boards placed diagonally in each square, extending the entire height of the filling. This gives an alternate thin film and drop formation of water, which exposes large and changing surfaces to the counter current of air. The construction of the filler gives rigid bracing of all boards at short intervals, preventing any possibility of warping.

Water is distributed at the top of the tower by a system of open V troughs and gutters, overflowing through notches in the side walls onto the top edges of the filling boards in such a manner that no splashing can occur and even distribution is insured. With varying amounts of water handled, the volume of the films varies but not the velocity nor the spray area. Impure water may be circulated without injury to the working of the tower or other trouble than occasional cleaning of the troughs with a broom.

At the base is a tank of concrete, brick or steel, from which water flows to the pipes leading to the condensers. This basin is designed for ready separation of impurities and their easy removal, any oil brought into the system being carried away by an overflow.



SECTION OF WHEELER-BALCKE NATURAL DRAFT TOWER

In the "Chimney Coolers" a casing is erected of wood or steel around and above the filling, this serving to augment the velocity of the air current through the filling because of the greater height of heated air column. The casing is a thoroughly braced frame lined with grooved and tongued cypress boards to withstand safely a wind pressure of 30 lb. per sq. ft. Or, if required, the casing may be of steel sheets on a structural steel frame, or of masonry or concrete.

Chimney coolers are provided with fans for use when the natural draft is insufficient.

In the open or Atmospheric coolers an open framework of wood or steel supports the cooling hurdles set in horizontal rows and so spaced from top to bottom that with the lowering of the temperature of the water an increased volume of air passes. To secure ample air circulation in calm weather, this type is preferably built in sections not exceeding 6 to 8 ft. in width to windward.

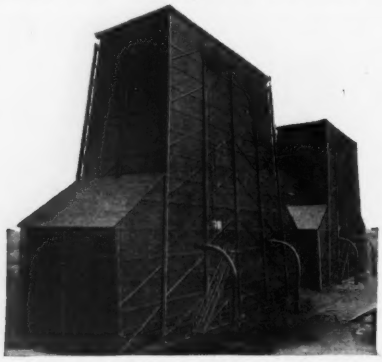
Stocker Forced Draft Towers

In the fan type towers manufactured by Geo. J. Stocker the filling and water distribution are the same as described for natural draft towers. Below the filling a chamber is provided into which fans, mounted in pairs at opposite sides, force the air for cooling. The main casing is the same as for natural draft, but a gallery is provided about the top which serves the double purpose of preventing winds for distributing the water in the distributing troughs and allowing, with the doors to the fan houses, access to all parts for cleaning and inspection.

C. H. Wheeler Natural Draft Towers

Natural draft towers made by the C. H. Wheeler Mfg. Co. have the water delivered into feeder troughs at the top of the tower, extending the entire width of the tower and feeding to a system of small V troughs open at the top and perforated in the lower side to form a large number of small equally distributing streams. Should the holes clog, the water overflows the edges of the trough in thin sheets, and the open top permits of ready cleaning while the tower is in use.

From the troughs, water falls upon a series of wood strips set on edge and alternate rows staggered, so that the streams of water are broken into spray, allowing the air to take up the heat readily. For the racks which support these strips, as well as for the strips, cypress is used as it is practically "decay proof." Each rack is bolted securely to the uprights of the main framework.



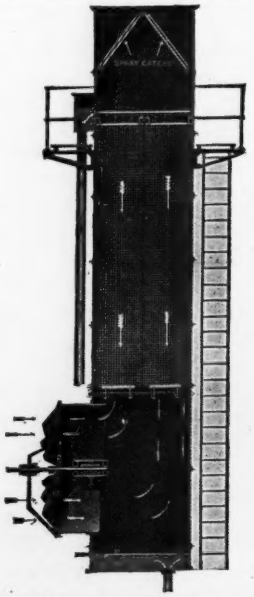
WHEELER-BALCKE NATURAL DRAFT TOWER

On the exterior is a system of louvers, with openings pointing upward and outward to permit free passage of air in a light breeze, yet prevent spreading of spray in a wind, thus saving water and protecting nearby property. Main framework and louvers are of long leaf yellow pine, impregnated under heat with carbolineum paint to give thorough waterproofing.

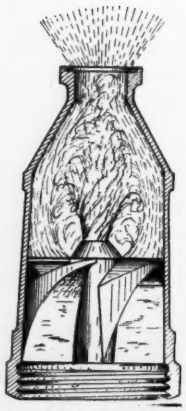
C. H. Wheeler Forced Draft Tower

Forced draft towers of the C. H. Wheeler Mfg. Co. are similar in distributing arrangement and interior construction to the natural draft type, but the sides are closed in with asbestos protected metal sheets carried on a steel framework, shell and framework being independent of the interior construction. In some cases treated wood siding is used in place of the metal sheets.

Air is delivered under forced draft by fans placed 2 on a shaft in hoods at opposite sides to the tower, as many fans being used as the size of tower calls for. The fans are of special design to move large volumes of air at low pressure, with blades of screw form, double galvanized and riveted to braces held by a central cast-iron disk. This disk has a split hub which is clamped by bolts to the steel shaft which runs in roller bearings at each fan. No bearings are exposed to the water. In large towers where a central bearing is needed, the entire shaft is shielded by a hood, and the ring oiling bearing furnished with oil by supply and overflow pipes carried to the outside of the housing. The housing, both sheets



SECTION OF WHEELER-BARNARD FAN DRAFT TOWER



AMERICAN SPRAY CO. NOZZLE

and framework can be painted all over by removing some of the adjacent wood strips inside, thus insuring proper maintenance.

Wheeler Condenser & Engineering Co. Natural Draft Tower

Wheeler-Balcke natural draft cooling towers as made by the Wheeler Condenser and Engineering Co., are designed to use natural or chimney draft to circulate the air, and for minimum lift of the water.

The cooling surface and water distribution system are arranged so as to offer least resistance, the drop and film principle being employed to secure maximum water surface.

The tower is built of cypress boards on a framing of yellow pine which rests direct on the foundation, and has mortise and tenon joints, bolted where necessary with steel bolts and large washers and calculated to withstand a 50-mile gale. All timbers are specially treated.

The shell boards are 1 in. cypress, tongue and groove, treated after erection with preservative to prevent decay.

Water is discharged from the main inlet into a trough of 1½-in. cypress boards and flows into lateral gutters which in turn distribute through iron pipes placed at equal intervals over the entire area of the tower. From these pipes the water falls upon galvanized steel splash plates, breaking into fine spray, then upon the triangular cypress cooling laths, which are arranged in zig-zag tiers as shown, being broken up, turned over

and spread out in a film to bring all portions in contact with the air current and give maximum surface.

Air enters at the base of the tower through louvers which prevent loss of water by splashing, conducting it to the cold well in the base.

On one side of the tower a working platform is built at the top of the cooling section, reached by ladder, protected by hand rail and giving entrance to the tower through a door so that the distributer may be cleaned while the tower is in service.

Wheeler Condenser & Engineering Co. Forced Draft Tower

Keeping the air in rapid motion to sweep it away as fast as it becomes saturated and replace it with dry air, at least energy expenditure, and providing a large water surface so that the air may quickly become saturated are the objects sought in the design of the Wheeler-Barnard cooling towers, made by the Wheeler Condenser and Engineering Co.

SPRAY SYSTEM OF AMERICAN SPRAY CO.

Large surface is provided by woven steel wire mats, galvanized after weaving, which act as metallic sponges and, hanging vertically close together, hold the water in thin films with free passages for air between. Water is distributed evenly over the top edges of the mats by galvanized iron troughs, arranged to be easily cleaned while the tower is in service, either in place with a stiff broom, or by lifting out one at a time.

The mat cooling system is enclosed in a rectangular steel casing having the beam reinforcement, and air current is supplied by impeller fans at one or both sides, driven from the extended shaft. Power required for condenser pumps and tower fans is only about 3 per cent of the indicated horsepower of the engines which the cooling installation serves.

American Spray Co. Nozzles

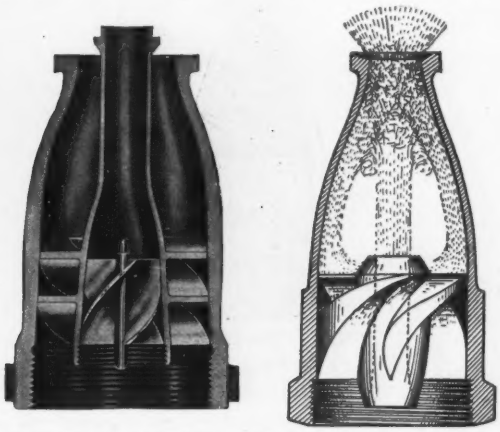
Low cost for installation, operation and maintenance are the features of the spray cooling system made by the American Spray Co. Water loss from evaporation is found by test to average about 1 per cent and seldom exceeds 1.8 per cent.

The nozzle used by this company is of the form shown in the sectional view, gives a fine uniform spray at 5 lb. pressure, and a fine mist at pressures exceeding 10 lb. Central and side jets are given a rotating motion which increases the centrifugal force at the orifice and gives uniform distribution of a solid dense spray.

Sizes recommended for cooling are shown in the accompanying table, the usual pressures being 3 to 6 lb. for winter and 6 to 8 lb. for summer running. Tests show that above 8 lb. pressure the gain in cooling does not warrant the extra expense of pumping. The amount of cooling depends as much on the design of the spray system as on the type of nozzle adopted. If the system is properly designed the water can be cooled to the temperature of the atmosphere, and on hot days to 5 or 10 deg. below the temperature of the atmosphere. A special provision in the spray system prevents drifting spray, especially in the winter time.

SIZES AND CAPACITIES G. P. M. OF AMERICAN SPRAY NOZZLES

Diameter of Supply In.	Diameter of Orifice In.	Pressure per Sq. In.			
		5 Lbs.	8 Lbs.	10 Lbs.	15 Lbs.
1-1/2	1/2	14	17	20	24
1-1/2	5/8	22	27	32	37
2	3/4	33	42	47	57
2	7/8	48	60	65	79
2-1/2	1	65	76	85	105
3	1-1/4	..	122	135	165
3-1/2	1-1/2	..	..	195	238
4	2	..	..	320	368



SECTION OF SCHUTTE & KOERTING SPRAY NOZZLE
NOZZLE USED IN SPRAY ENGINEERING CO.'S SYSTEM

Schutte & Koerting Spray System

The Koerting multispray nozzle is of the double spiral type designed to operate at pressures of from 5 to 10 lb. This nozzle is built on the centrifugal principle, the spirals giving a whirling action to the water which causes it on issuing from the nozzle tip to spread out in a finely atomized cone spray. The main spiral has a hollow center in which is fitted a smaller spiral, a construction which produces 2 distinct cones of water, the effect of which is to give intimate contact of water

and air and thereby secure effective and uniform cooling.

When set in rows, the nozzles are inclined at 60 deg. to the horizontal to give effective circulation of air through the spray.

Sizes and capacities at different pressures are as follows:

Capacities in Gallons per minute at various pressures

Size of Nozzle In.	Lbs. 5	6	7	8	9	10
2	54	60	65.5	70.5	75	78
2½	77	85	92	98	103	106
3	115	125	133	140	146	151

Spray Engineering Co. System

Extended experience of the Spray Engineering Co. has gradually resulted in the nozzle as shown. Design of the nozzle center is such that water enters in a direction parallel to the stream flow and is gradually changed to a direction at right angles to it and tangential to the axis. By this means the water friction is greatly reduced, and mingling jets produce a solid cone of fine drops. A high grade of bronze smoothly finished is used for both shell and center, and ample metal is provided at wearing points, insuring a low rate of depreciation.

By reason of the improvement in these spray nozzles the power necessary to operate the spray system has been reduced fully 50 per cent over what was formerly thought necessary.

BINKS SPRA-RITE NOZZLE

In most parts of the United States a spray system will cool the water sufficiently to afford an average vacuum of 28 in. or 2 in absolute, throughout the year, and an average vacuum of 27½ in. in the hottest weather.

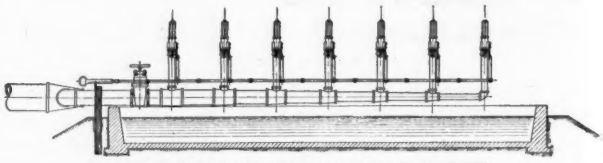
Drift losses are small, due to the low pressure, from 3 to 6 lb., at which the spray system operates, as the particles of water while broken into a fine spray are yet of sufficient size to settle within the limits of the pond, so that spray installations operate within 40 ft. of buildings without inconvenience. Tests have shown that the yearly average loss of water from evaporation and drift with the spray system will be not over 1½ per cent of the condensing water used.

Star Brass Works Nozzle

The Binks Spra-rite nozzle is made by the Star Brass Works in sizes from 1/16 to 1½ in. orifice for ¼ to 3-in. pipe. As shown, a worm is used to give rotary motion to the water, which striking the lugs at the end of the worm is deflected and shot through the nozzle in a solid mass of spray, giving great cooling effect.

Thomas Spray Head

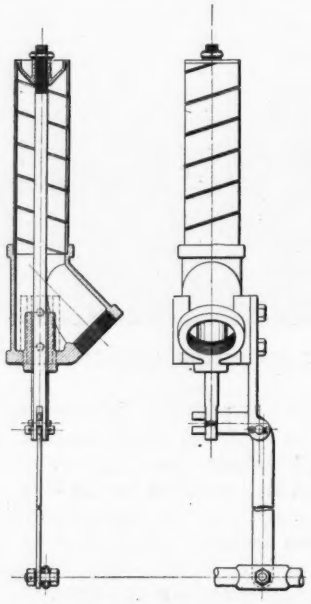
In the Thomas spray head made by the C. H. Wheeler Mfg. Co., a spiral tube of bronze is held by a cast-iron base and the cap, which is screwed to a central bronze stem, can be raised or lowered to control the opening between turns of the spiral. The stem, which slides through a close clearance bushing, is operated by a bell crank whose horizontal arm engages a pin in the bottom of the stem, the vertical arm being operated by a rod



ARRANGEMENT OF THOMAS SPRAY SYSTEM

from the side of the spray pond, to give accurate control of the fineness of the spray, also to permit opening the nozzle to allow foreign matter to pass out of the slots and above the end of the spiral tube, when the cap is in highest position.

Due to the angle of the slot, the water is thrown in an upward direction as a continuous sheet, spreads and becomes thinner, until it breaks into uniform spray. The adjustable feature provides for regulating the thickness



SECTIONS OF THOMAS SPRAY HEAD

of the sheet according to the quantity of water circulated, wind velocity and atmospheric conditions, thus minimizing drift of the spray and permitting maximum effect in still, hot weather.

Pressure required to force the water through the nozzles is 2 to 4 lb., for the spiral slot is 5 ft. long, and flow from it begins as soon as water enters the nozzle.

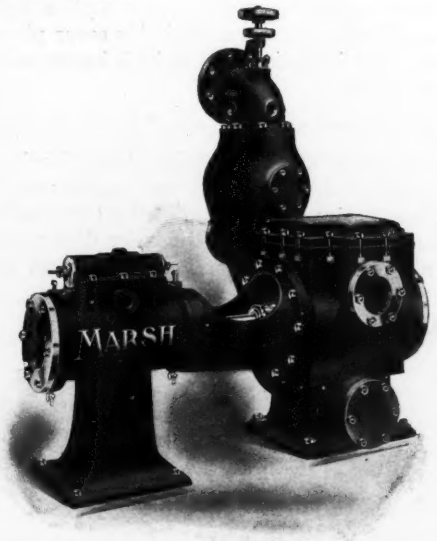
By removing the pin and nut at the bottom of the stem, the cap and stem may be taken out and the spiral lifted from the base, leaving all parts free for inspection and cleaning.

Condensers Received Late

Marsh Jet Condensers

Shown herewith is a Marsh vacuum pump and jet condenser as built by the American Steam Pump Co. The pumps used in conjunction with these condensers are of the regular Marsh make, equipped with Marsh self-regulating steam valve fully explained elsewhere in this issue.

The condenser proper is a pear-shaped casting bolted to the suction of the pump and fitted above with an elbow for the introduction of the injection water, which instead of being emitted inside of the condenser cone in the form of spray, assumes the form of a cone-shaped envelope through which the exhaust steam, introduced through an opening on the side of the shell, must pass. In doing so, the steam and water are brought into intimate contact, the former condensing and together with the injection water and entrained air falls to the bottom of the air chamber from where it is removed by the vacuum pump. The rate of flow of the injection water is regulated by means of small hand wheels located on top of the elbow.



MARSH VACUUM PUMP AND JET CONDENSER

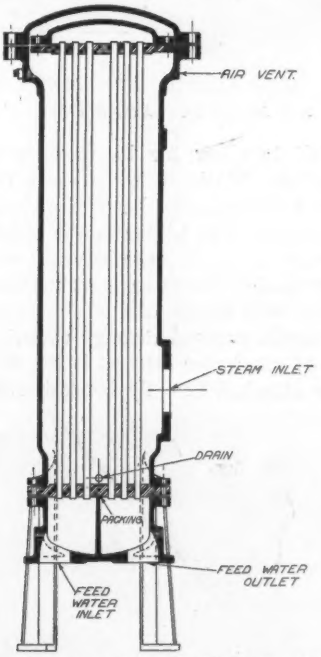
Another condenser of the jet or spray type used in connection with Marsh vacuum pumps and designed primarily for the handling of returns from heating systems is the Waters condenser, which consists of a short section of piping bolted to an elbow connected to the suction of the pump. The flanged opening on the side allows the introduction of steam while the injection water enters through a fitting in a blind flange on top.

Goubert Surface Condenser

In the accompanying illustration is shown a sectional view of a Goubert surface condenser arranged for installation in a vertical position. This condenser consists of a cast-iron shell and heads mounted upon supporting legs and contains a series of 1-in. O. D. number 18 B. W. G. seamless drawn brass tubes expanded into cast-iron tube plates at each end. No glands are employed, as all longitudinal expansion is taken care of by floating-head construction.

Steam enters the shell through an inlet located at a distance of about ⅓ of the height of the condenser, while cooling water is brought in through an opening at the bottom of the lower head. Due to the presence of a cast partition in the lower head, the water rises in the left-hand bank of tubes to the top where, by means of a cap bolted to the upper tube sheet, it is directed downward through the right-hand bank, back to the lower head and out. The condensed steam is removed by means of a drain located in the side of the shell directly above the lower tube sheet.

The manufacturers of the Goubert Condenser, The Griscom-Russell Co., also build so-called overflow condensers for use when the cooling water available is of such character as to necessitate arrangement for cleaning the surfaces while the condenser is in operation. In these the condensing surface is of boiler tubes rolled into sheet steel headers at each end, no provision being made



SECTIONAL VIEW OF GOUBERT SURFACE CONDENSER

for expansion other than the deflection of the heads into which the tubes are rolled. This type of condenser is for installation in a vertical position only. The admission of cooling water is arranged for either at the bottom of the shell, the water passing upward through the tubes and overflowing, or at the open top, the water passing downward through one-half of the tubes and returning upward through the other half to an overflow. The head of the condenser is open and permits of passing a tube cleaner through the tubes while the unit is in operation.

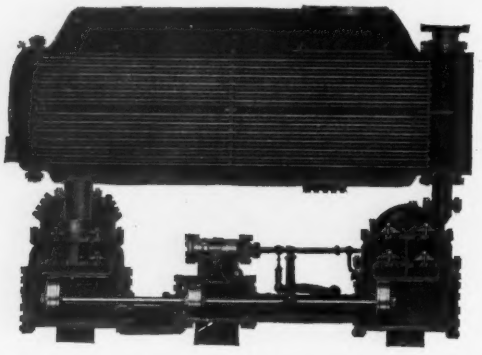
Wheeler Surface Condensers

Wheeler Condenser & Engineering Co. manufacture 2 general types of surface condensers, namely, the Wheeler Admiralty surface condenser and the Volz combined surface condenser and feed water heater.

The first of these consists of a rectangular or cylindrical shell, the ends of which are closed by brass plates or tube ends, connected by small brass tubes passing

through the plates from end to end of the condenser. The tube heads are drilled and tapped and small ferrules are screwed in to compress the packing to avoid leakage and prevent the tubes from working out of place.

The shell is usually constructed of cast iron, although for marine work it may be made of steel or copper to save weight. A large space is provided where the steam



WHEELER ADMIRALITY SURFACE CONDENSER AND COMBINED AIR AND CIRCULATING PUMP

enters the shell to allow for its uniform distribution among the tubes. While in some cases the water is passed but once through the bank of tubes, it is more usual to provide division plates in the water chambers so as to cause the water to make several passes.

Exhaust steam from the engine or turbine enters the condenser shell and is distributed between the tubes while cold water is pumped through them.

A feature of particular interest is the indicating hot well, which is attached directly beneath the condenser, the opening in the bottom of which is so built that the condensate drains into the left-hand chamber of the hot well. Communication from this chamber to the hot well pump suction is secured through an orifice carefully formed in a brass plate, and placed in the dividing wall. As the velocity of discharge through an orifice of given diameter varies directly as the square root of the head, and the quantity of water discharged is equal to the product of this velocity, the area of the orifice and the coefficient of contraction, it is readily seen that with a properly designed orifice the quantity of discharge is obtained with a high degree of accuracy by an indicating gage glass placed conveniently and calibrated in pounds of steam per hour.

Ball check valves are provided in each gage glass fitting, so that should the glass break, inflow of air will be prevented and the glass allowed to be replaced at leisure.

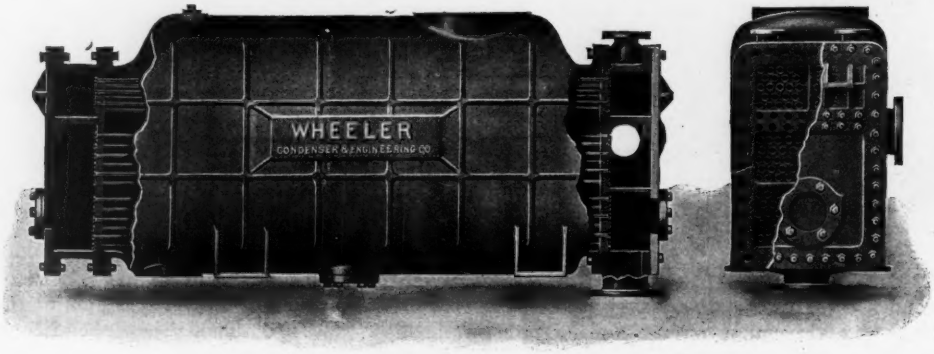
In water works service, where the entire volume of water pumped is pased through the condenser and requires a large volume of flow area, it has been found desirable to pass the exhaust steam through the tubes and allow the cold water to circulate around them.

Volz Combined Condenser and Heater

Externally, this combined condenser and feed water heater is similar in appearance to the regular Admiralty type of surface condenser; internally, as shown, its construction is somewhat different. The feed water heater is incorporated in the upper part of the shell, certain tubes being set aside for heating the feed water and communicating at either end with suitable inlet and outlet passages separate from the regular circulating water passages. These tubes, which are of the same size as the condenser tubes, are placed near the entrance of the exhaust steam and as a result receive the full benefit of its high temperature. The water chamber tube head division plates are composition cast in one piece and made to withstand boiler pressure. Suitable cover plates provide free access independently to both heater tubes and condenser tubes.

Blake-Knowles Automatic Jet Condensers

The Blake & Knowles Steam Pump Works manufactures 3 general types of jet condensers, namely, the Spray Pipe, Adjustable Cone and the Counter-Current condensers, the first 2 of which are for direct mounting on the air pump, while the Counter Current unit requires the use of a wet-vacuum pump and a dry air pump, and if so desired, may also be employed as a "barometric," in which case, however, no wet vacuum pump is necessary.



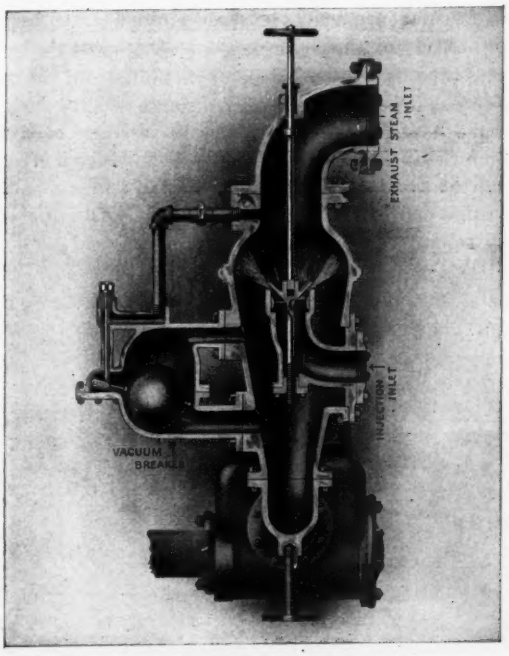
VOLZ COMBINED SURFACE CONDENSER AND FEED WATER HEATER

Adjustable Cone Jet Condenser

This condenser is of pear-shape construction and is provided with an adjustable cone for regulating the thickness of spray and quantity of injection water, and furnishing a convenient means of flushing the condenser. In the larger sizes the cone adjustment is arranged with the hand wheel on the side of the condenser body instead of on top, in which case the upper elbow is omitted entirely.

Exhaust steam from the turbine or engine enters at the top, and upon being brought into contact with the upwardly directed spray is condensed. It then falls to the bottom of the condenser and is removed by the air pump. The supply of injection water should not be controlled by the cone, but by a gate valve fitted in the injection pipe line close to the condenser for that purpose. During operation, however, the gate valve should be left open and all adjustments made with the cone.

To prevent the water in the condenser rising above the proper level, an automatic-break vacuum safety attachment is provided. If by accident the air pump should stop while the engine is in operation, the water will rise in the condenser and when it has reached a



BLAKE-KNOWLES ADJUSTABLE CONE TYPE CONDENSER

certain level, lifts the float which in turn raises the relief valve from its seat, thus admitting air into the condenser and destroying the vacuum. As soon as the pump is again started, the float drops to its normal position, the air valve closes and condensation is resumed.

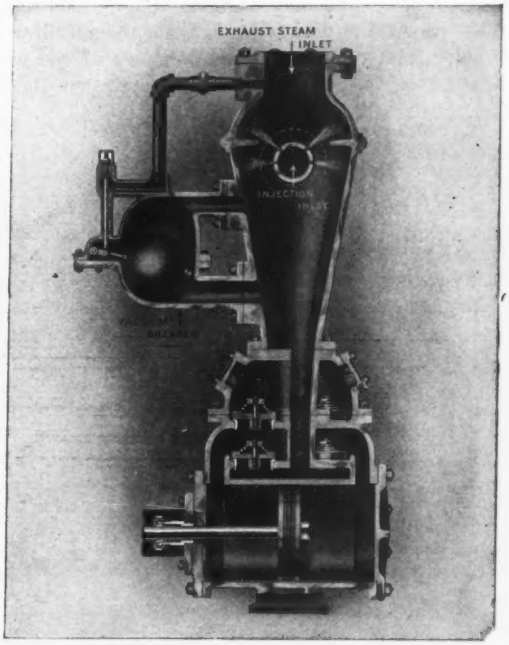
Spray Pipe Jet Condensers

Condensers of this type are similar in general construction and are fitted with the same break vacuum safety attachments as the condensers of the adjustable cone type, but a "spray pipe" takes the place of the elbow and cone. Injection water enters through long, narrow slits in the spray pipe which extends across the interior space of the shell, the requisite amount of water being admitted in thin sheets that completely condense the steam during its passage. The spray pipe is removable and can be quickly cleaned.

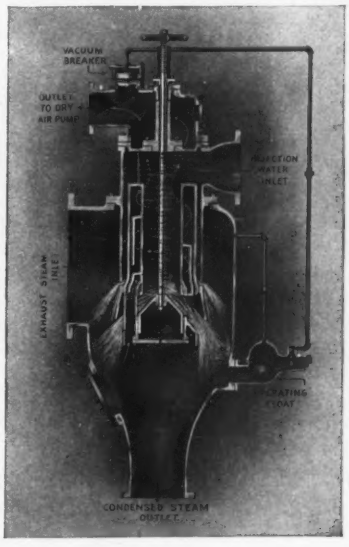
Counter-Current Jet Condenser

In these the air and water are handled by separate pumps, the condensed steam and injection water being removed by means of a wet vacuum pump, while the air is conducted and cooled through suitable passages to the condenser top and taken away by a dry air pump of the rotative type.

Injection water entering the condenser near the top flows down through a center and concentric water chamber to a point a trifle below the center line of the exhaust inlet, where by means of adjustable openings, it



BLAKE-KNOWLES SPRAY PIPE TYPE CONDENSER



BLAKE-KNOWLES COUNTER-CURRENT JET CONDENSER

enters the condensing chamber in the form of a spray and intimately mixes with the steam to be condensed.

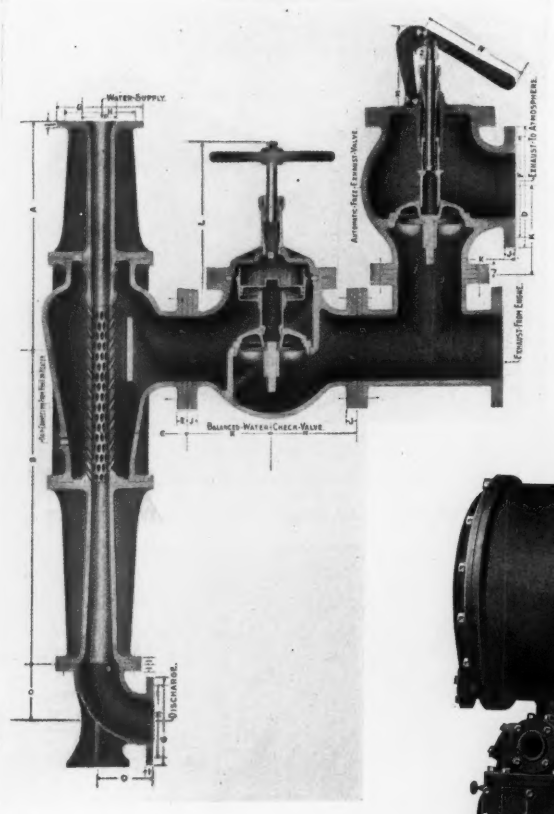
On the right of the body of the condenser and just above the throat is attached an automatic break vacuum safety attachment, in general the same as that used with the adjustable cone and spray pipe types described above.

Eynon-Evans Exhaust Steam Condensers

The general principle upon which this condenser operates may be readily understood from a study of the accompanying illustration, which is shown a cross-section showing its interior construction. In general, it consists of a perforated tube first diverging and then converging in cross section with the perforated section surrounded by a pear-shaped steam chamber. Exhaust steam enters at the right through the balanced water check valve, and due to the high velocity of the water in the narrow section of the tube, is drawn therein, where it mixes with the injection water, is condensed and carried away. In order to facilitate this action, the perforations in the injection water tube are given a downward direction toward the interior of the tube, resulting in an action similar to that of an injector. A baffle plate, shown at the steam entrance at the right, prevents the entering steam from coming into direct contact with the tube, and in order to remove any water which may collect at the bottom of the steam chamber, a suitable connection is provided whereby any water so collected may be carried away and returned to the system.

When connected as shown, no provision for breaking the vacuum at the condenser is required, as should this become flooded and the water rise to a dangerous level, the balanced water check valve will close, shutting off the steam, causing it to then pass out through the automatic exhaust valve to the atmosphere.

This condenser is made by the Eynon-Evans Manufacturing Co.



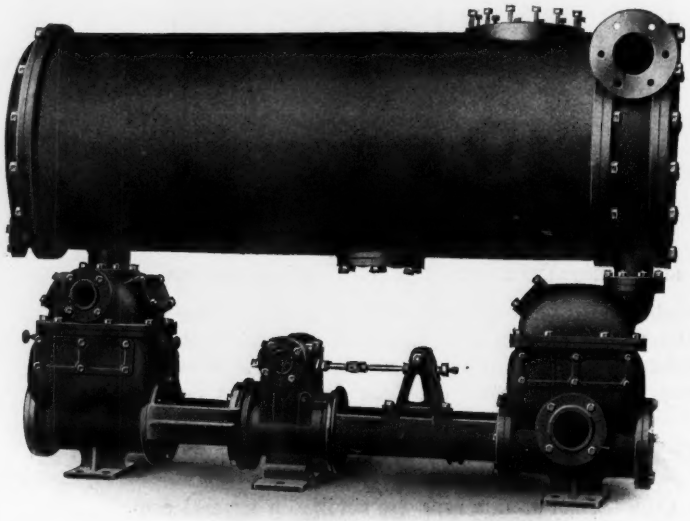
SECTION OF EYNON-EVANS EXHAUST STEAM CONDENSER, BALANCE CHECK AND FREE EXHAUST VALVE

Blake-Knowles Surface Condensers

These condensers, the main castings and water bonnets of which are made of close-grained cast-iron, are built in sizes covering almost every requirement.

The tube heads are independent plates and the tubes of seamless drawn brass passed through stuffing boxes in the tube heads provided with brass ferrules, each with a lip on the inside which prevents the tube from creeping and at the same time permits expansion and contraction. The tubes can be readily removed and the stuffing boxes easily repacked.

Unless required to meet special conditions the exhaust steam inlet is located in the top of the shell, while the circulating water inlet may be found at the bottom of one end of the condenser with the outlet for this water directly above and at the same end.



BLAKE-KNOWLES SURFACE CONDENSER MOUNTED OVER COMBINED AIR AND CIRCULATING PUMPS.

Bonnets and cover heads are provided with suitable openings so as to permit ready inspection.

When not intended to be mounted upon air and circulating pumps, these condensers are provided with cast-iron saddles suitably arranged to rest upon foundations, iron beams or columns as the case may be.

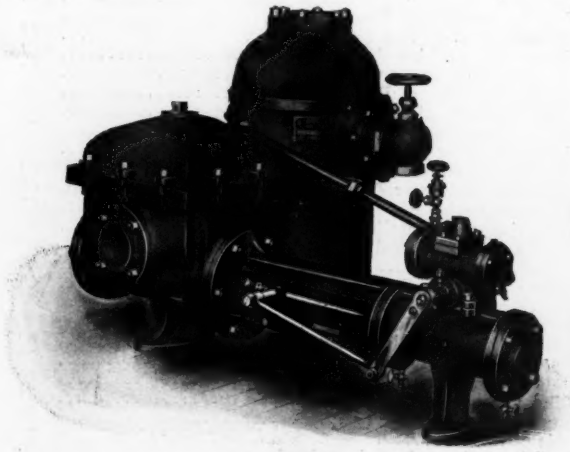
Blake-Knowles Surface Condensers are built by the Blake & Knowles Steam Pump Works.

Davidson Independent Air Pump and Jet Condenser

This consists of an independent air pump and jet condenser as illustrated. Exhaust steam enters the top of condenser and is brought into contact with a fine spray of cold water coming in an opposite direction through a copper spray pipe, and is thereby condensed and a vacuum formed. The air pump which is placed alongside the condenser removes the condensed steam, injection water and vapor.

A Davidson automatic vacuum breaking device, consisting of a float operating a valve opening to the atmosphere is provided, thus making it impossible for the water to back up and prime the engine's cylinders, if, due to any accident, the air pump should suddenly stop.

A single condenser can be used for 2 or more engines, pumps, etc., one or more of which may be started or stopped without interfering with the action of the condenser.



THE DAVIDSON INDEPENDENT AIR PUMP AND JET CONDENSER

These condensers and air pumps are well adapted to marine engines and may be used as a bilge pump when required.

M. T. Davidson Co. is the manufacturer of these units.

Scranton Jet Condensers

These condensing units, which are built integral with the pump to handle the air, condensed steam and injection or condensing water, are of a construction said to be such that it is practically impossible to flood the steam cylinders of the engine with which they operate.

Exhaust steam from the engine or turbine is delivered to the top of the condenser through a large elbow and directed into an exhaust nozzle surrounded by a water supply chamber. Condensing water entering the side of this chamber overflows around the top of a converging condensing chamber where it is brought into intimate contact with the steam. The condensed steam, water and noncondensable vapors are then taken up by the suction of the pump below and discharged.

The condensing chamber which is ordinarily cast in 3 sections, is bolted to the water cylinder of the pump as shown. The injection water is regulated by means of a valve on the outside of the condensing chamber which eliminates the use of internal spray valves.

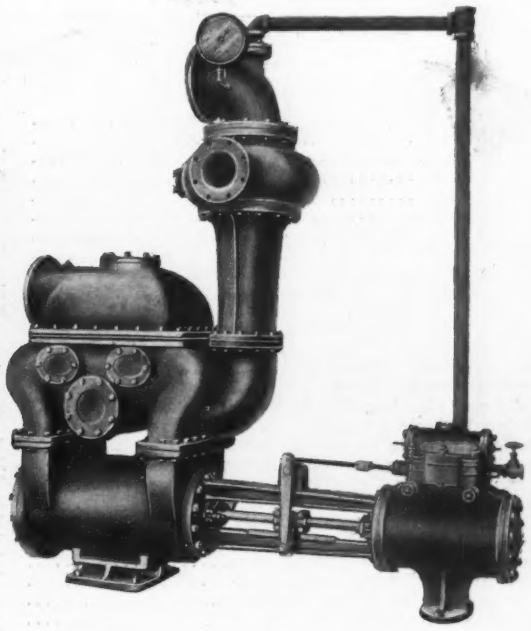
With the smaller sizes of condensers, single-cylinder pumps are employed, while in the larger ones, duplex pumps are generally used, and if conditions so require, one air pump may be provided with 2 condensers by using a specially constructed suction valve chamber.

To utilize the exhaust steam from the pump, this is generally discharged into the condenser together with that from the engines or turbines.

Scranton jet condensers and vacuum pumps are made by The Scranton Pump Co.

Beyer Barometric Condenser

In the Beyer Barometric Condenser, built by the Ingersoll-Rand Co., full counter-current effect is obtained in the mixing process between the steam and water. Exhaust steam to be condensed enters at the bottom of the condenser head, and the cooling water at a point above into a pool, the edge of which is concentric with the outside shell. The water starts from a position of rest and flows over the edge of this pool, falling over a series of inverted cones and baffles, the latter being attached to the walls of the shell in such a manner that the falling water completely envelopes the entering steam. The water and steam flow in opposite direction, obtaining a high degree of condensation with a given volume of cooling water, an action intensified by previously ridding the cooling water of its air content.



SCRANTON JET CONDENSER

A moisture separator is placed at the top of the condenser chamber, through which the air removed must pass before reaching the air pump. A large opening is provided for the removal of the air, resulting in a low velocity, and by the change in its direction through separation of the moisture content takes place, the dry air being drawn off by the air pump.

Illustration of this condenser will be found on page 1.

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1916

What lies ahead? A year of struggle is past. Deadly combat, fears for the position into which our own Nation might be forced, industrial uncertainty, distrust and misunderstanding among nations and fellow citizens. Will the year before us see the end?

Industries are reviving in all directions, crops are bountiful and prices high. Reports indicate that our sister nations to the south are turning to us for capital and the products of our factories. All seems of fair promise.

In our own housekeeping many things must be settled; a president to elect, a policy as to defense to determine, what, if any, revival of maritime prestige shall be secured, and how—and readjustment of national income and expenses by increasing the one, curtailing the other or increasing both together.

Practical Engineer does not deal with politics. Its editors are not statesmen, but it believes that every reader wants to do his duty as a sovereign citizen of this republic, and trusts that he will give such study and thought to these great national questions as will enable him to decide what he believes should be done—then to do his part towards getting it done.

Here's hoping that before the yearly figures change again, the Earth may be at lasting peace; that all may prosper much and worthily progress in all good ways and "God go wi' ye all and ye wi' Him."

The Lowly Pump

Often tucked in a dark corner, given no attention except an occasional dose of oil, expected to deliver when the valve is opened, and to run as long as steam is supplied, blamed while it runs for its great appetite for steam and doubly cursed if it doesn't run—such is the fate of the feed pump.

Yet it is deserving of better things. If it fails, what use the eddying furnace flame? It can but destroy the boiler. What service the whirling turbine? It will but hasten the boiler's hurt. And then the pump gets the attention it deserves—is coaxed, tended, prayed (?) over or kicked until once more it takes up its steady routine—and is again neglected.

Why not give the pump, boiler feed or other, its rightful place. You need it—and most when other things are going wrong. It should have at least as good care and chance to do its duty as any machine in the whole plant. It is a sturdy, reliable servant, or it would never survive the treatment usually given it. The servant is worthy of his hire.

Condensers

Here again is a case of tuck it in a hole. And this time economy usually requires such location to get short connections. But a condenser is an inverted boiler, and if its tubes are scaled and dirty, if its circulation is poor, either vacuum suffers or power to operate it is too great. Leaky tubes may not put it out of commission, but they reduce effectiveness as certainly as in a boiler.

And so room to inspect, to test, to overhaul and repair are essential. As well as keeping *its* pumps always ready and willing. Light is the enemy of dirt and neglect. A few extra incandescents placed to reveal all parts of the condenser—not sockets for an emergency work light, but real permanent lighting—are a good insurance investment against a shut down or "running lame" because the condenser is "out" and the engine must exhaust atmospheric.

Recooling

Design of a cooling system, as it depends so much on variable factors is always somewhat of an uncertainty and success depends largely on judgment guided by experience. But it isn't any great mystery, and the facts and factors gathered in this issue will help to an understanding of the conditions which must be fulfilled. Will it pay? is the first and last question. Careful study of the data presented, with costs of water and for installation which must be secured for any given problem will enable any engineer to get a good idea of the answer and determine whether it will pay to go into detail.

Since experience is so large an item in successful design, the home-made system for recooling is hardly to be advised, though it may give reasonably good results. The chances are, however, that the slight extra cost of getting experience of those in the business will be well repaid by the bettered results. Where a cooling system is worth while at all, water is precious; a saving in make-up water, or a few degrees more of cooling may add mightily to the efficiency of plant operation. Here, especially, it "pays to get the best."

U. S. Civil Service Commission announces an examination for sanitary engineer, on Jan. 19, 1916, to fill vacancies in Bureau of Science, Manila, P. I., at salaries of $1600, duties to involve engineering problems with regard to water supplies, sewage disposal, rat-proofing construction and drainage, and the preparation of plans and specifications for such projects. Applicants must show that they have graduated in sanitary engineering from a college or university of recognized standing, or that they have had at least 4 yr. experience in sanitary engineering work, must have reached their twenty-first but not their fortieth birthday, and must submit to the examiner on the day of the examination their photographs, taken within 2 yr. Apply for Form B. I. A. 2, stating the title, Sanitary Engineer (Male), $1600, to the U. S. Civil Service Commission, Washington, D. C.

THE RECENT PUBLICATION issued by The Wm. Powell Co., of Cincinati, is a 20-page booklet on the company's White Star valve. This book briefly but completely discusses the function of these valves, and illustrates in sections the several types made by the Wm. Powell Co. The booklet contains full information as to construction, operation and prices. The company will gladly accede to requests for copies.

ARMSTRONG STEAM TRAP is the subject of a circular explaining the new operating principle of the trap manufactured by Armstrong Machine Works, Three Rivers, Mich.

METAPHRAM damper regulators, which are all metal and are designed for any shape of boiler, are described and illustrated in a folder from National Regulator Co., 208 S. Jefferson St., Chicago.

CALYX CORE DRILLS are the subject of a 128-page publication, Form No. 9201, issued by Ingersoll-Rand Co., 11 Broadway, New York. Setting up and operating calyx drills are fully explained with reference to conditions generally encountered in prospecting, well drilling, sounding, etc. Many interesting views illustrate the drills in contract work, stone quarrying, coal and metal mining and well drilling in various countries.

FRANCE VANADIUM calendar for 1916 has just been received from France Packing Co., of Philadelphia.

CATALOG C from The Reliance Gauge Column Co., of Cleveland, Ohio, deals with the construction and advantages of the Cleveland friction clutch.

THE TERRY TURBINE is the title of a new bulletin giving a general description of the various turbine applications, and dealing particularly with various kinds of high, low and mixed pressure turbines. The Terry Steam Turbine Co., Hartford, Conn., will be glad to supply copies to those interested.

BULLETIN NO. 38 of the U. S. Department of Agriculture, "Methods for the Examination of Bituminous Road Materials," which has been extensively used as a manual and handbook by engineers and chemists, has been revised and amplified by specialists in the Department and in its new form has been issued as Bulletin No. 314.

This bulletin, which covers 49 printed pages, is designed to present the methods now in use by the Office of Public Roads and Rural Engineering of the Department in such a way that with a little practice and the proper equipment any engineer or chemist may make an adequate examination of bituminous road material. The various tests are described in some detail and illustrations of practically all of the apparatus required have been included. Special attention is called to modifications in the penetration test, the determination of fixed carbon, and determination of paraffin scale. New methods have also been substituted for the old distillation tests and for determination of voids in the mineral aggregate.

PRACTICAL ENGINEER

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Position Wanted

POSITION WANTED—As engineer. Have had 16 yr. practical experience in operating Electric Light and Refrigerating power plants efficiently and economically. Capable of making all repairs. Address Practical Engineer, Box 415, Chicago, Ill. 1-1-1

POSITION WANTED—By man with 18 yr. practical experience—4 yr. in general repair shop and 14 yr. in running engines. Have had considerable experience with Electric Light Plants, Flour Mills, as night Superintendent of Water Works, and Engineer in Oil Mill. I prefer night work (compressors) in Oil Mill if steady work. 36 yr. old. Married. Sober and steady worker. References. At present employed but desires change. Address Practical Engineer, Box 416, Chicago, Ill. 1-1-1

POSITION WANTED—As chief engineer. Have had extensive experience in operating, overhauling and erecting ice making, packing house and cold storage plants. Efficient and economical. Best results assured. Address Practical Engineer, Box 417, Chicago, Ill. 1-1-1

POSITION WANTED—By operating engineer, age 30, 6 yr. experience with Corliss and high speed engines, direct-current generators and motors, and gas engines operating from automatic suction gas producers. Best of references. Address F. J. Forboul, Beaver Dam, Wis. 1-1-1

POSITION WANTED—Chief Electrician. Young man having had long experience in installing, maintaining and repairing in A.C. and D.C. plants, desires to take charge where improvements in motor operation will be welcomed. Address Practical Engineer, Bo 409, Chicago, Ill. 11-1-4

POSITION WANTED—As advanced sales prospect man with firm manufacturing or selling power plant machinery, by thoroughly practical engineer with several years' traveling experience. Can furnish my own auto if desired. Address Practical Engineer, Box 412 Chicago, Ill. 12-15-2

POSITION WANTED—As operating engineer; perfectly at home in either electric lighting or ice plants; 15 years' continuous experience. Married, sober and reliable man. Address E. S. C., care Practical Engineer, Chicago, Ill. 11-15-3

POSITION WANTED—Chief engineer, now employed, wants change. With present company 10 years. Understands ammonia refrigeration. air compressors, pumps, etc. All electrical repairs—A.C. and D.C., phone wiring, etc. 72 per cent boiler efficiency last year. 35 years old. American. What have you to offer. Address Box 415, Practical Engineer, Chicago, Ill. 12-15-2

POSITION WANTED—By a young man, experienced operating engineer in both steam and electricity, as manager of light plant in a town of from 2,000 to 5,000. Can show a good record as an organizer. Full qualifications and references upon request. Address Box 374H. Practical Engineer, Chicago, Ill. 12-15-2

POSITION WANTED—Manager, experienced in brass sheet, tube, wire and stamped and screw machine products manufacture, ready for prompt engagement. Technical and sales ability. Full references available to proper parties. Age 31. Address Yankee, care Practical Engineer, Chicago, Ill. 12-15-2

Help Wanted

WANTED—A refrigeration engineer in Western Pennsylvania. Must be familiar with refrigeration, ice making, gas engines and electrical machinery. Raw water and evaporating system. State salary wanted. Address Practical Engineer. Box 418, Chicago, Ill. 1-1-1

WANTED—Resident subscription agents in the following cities: Atlanta, Ga.; Cincinnati and Columbus, Ohio; Kansas City, Mo.; Los Angeles, Calif.; Louisville, Ky.; Newark, N. J.; New Orleans, La.; Portland, Ore.; St. Louis, Mo.; San Francisco, Calif.; Washington, D. C. This is an excellent chance for a hustler, who is familiar with power plant conditions, to turn his spare time into dollars. To such a one we offer a Real Opportunity. Write Subscription Department, Practical Engineer, 537 S. Dearborn St., Chicago, Ill. tf.

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WANTED—One Corliss, steam-driven refrigeration machine, 150 to 30 ton capacity, with oil traps and condensers. One belt-driven refrigeration machine, 15 to 30 ton capacity, style horizontal or vertical, in first-class condition. Address Universal Ice & Cold Storage Company, Monongahela City, Pa. 1-1-1

WANTED—Agents handling engine and boiler-room specialties in every section for side line paying large commissions. Give experience, line carried, and territory covered. Address Practical Engineer, Box 381, Chicago, Ill. tf.

WANTED—Agents on commission to sell our Shaking Grates. We will install grates on trial or put in on test at our expense with any grate made. Address Armstrong Mfg. Company, Springfield, Ohio. tf.

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FOR SALE—(Model) Corliss Engine castings, cylinder 2 by 4½ in. Ask for circular. F. L. Peterson, 14 Bourne St., Worcester, Mass. 1-1-1

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BOILERS: (two 250-hp. Heine water-tube boilers, 150 lb., $950 each; (four) 300-hp. Sterling water-tube boilers, 150 lb., $1100 each; (one) 500-hp. Sterling water-tube boiler, 200 lb., $1750. 110-volt lighting dynamos, General Electric make; 30-kw., $200; 25-kw., $175; 20-kw., $160; 14-kw., $140; 9-kw., $100. Duzets & Son, 50 Church St., New York, N. Y. tf.

Patents and Patent Attorneys

PATENTS—C. L. Parker, Attorney-at-Law and Solicitor of Patents. Patents secured promptly and with special regard to the legal protection of the invention. Handbook for inventors sent upon request. Washington, D. C. tf.

PATENTS—H. W. T. Jenner, Patent Attorney and Mechanical Expert, 606 F St., Washington, D. C. Established 1883. I make a free examination and report if a patent can be had, and the exact costs. Send for full information. tf.

A. P. CONNOR, Consulting Electrical and Mechanical Engineer. Attorney-at-Law and Solicitor of Patents and Trade-Marks. Results guaranteed. 121 Carroll St., S. E., Washington, D. C. tf.-x

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ENGINEERS AND FIREMEN—Send 10c in stamps for a 40-page pamphlet containing a list of questions asked by an examining board of engineers. Stromberg Publishing Co., 2238-A Pope Ave., St. Louis, Mo. E.O.I.-tf.

Miscellaneous

ENGINEERS, DO YOU WANT to utilize your exhaust steam for heating or drying purposes, without back pressure on your engine? If so, address Monash Engineering Co., 1413 W. Jackson Blvd., Chicago, Ill.

Inventions

INVENTIONS commercialized on cash and royalty basis. Inventors and manufacturers should write Adam Fisher Mfg. Co., 2175 Railway Exchange, St. Louis, Mo. tf.

Sparks From The Advertising Pages

Way back in 1837, so the files in Washington show—one of the examiners of patents sent in his letter of resignation stating therein that "all of the great inventions have now been made, and henceforth the work of the patent office will deal mainly with small improvements on existing inventions, and with other routine work."

Was there ever a better example of short-sightedness than this?

Think of it—**1837**—the age of the kerosene lamp—the slow and tedious methods of transportation—no telegraph—no cable—no farm machinery—no automobile—no typesetting machinery and no movies.

Now, what has happened in the way of discovery and invention since then—what things new have come within your own range of vision and experience—you who read the modern magazine and trade journals from cover to cover. It would be impossible to enumerate the many devices brought forth since 1837 that are a benefit to mankind—and to classify the marvelous progress in the realms of medical and surgical science since that date, or even to mention the many reductions in the habits of men that are now considered economic wastes, gnawing at the vitals of efficiency.

The length, depth and breadth of every existing superlative in any language would not be great enough to take in the expression of the discouraged patent examiner were he to wake up today and see mere man toasting his toes on a coil of iron or to watch him touch a button on the wall and send a flood of light to every nook and cranny of the room, or to see him pick up an instrument nearby and talk to a friend in another part of the town, state or country, or to hear him produce accurate reproductions of vocal, instrumental or ensemble music right in his own parlor.

And these are only a few of the things that he might do in 1916 that he could not have done had he lived in 1837.

Still new inventions—new discoveries—new methods continue to come. One idea brings forth another—and a new invention or discovery may start a train of thought on an entirely different tangent and into realms that yesterday were unknown. So do not lament the fact that you were borne after Marconi, Wright Brothers, Edison, Maxim, Westinghouse and the host of other well known inventors of this decade. There are fields yet undiscovered and there are problems yet unconquered and natural laws yet to be bent to the will of man. The possibilities of the mind are illimitable.

To run away with the fallacious belief that all great problems which challenge the brain and patience and inventive inclination have already been met is to inoculate yourself with a germ almost as detrimental as the hookworm.

Get busy with your dreams and make them realities.

In the advertising and editorial pages of this issue you will find descriptions and announcements of many devices unknown in 1837, yet they are economic necessities now. Some of them you are perhaps using in your plant—others you ought to use if you intend to keep abreast of the times. Go over these pages carefully and find out what you need—then get in touch with the manufacturer and secure the full facts. But by all means don't get the idea that the world is "at the end of its tether." To give up in 1916 is infinitely worse than it was to give up in 1837.